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# Methods to Reduce Sand Ejecta from Projectile Impact – a Scaled Study with the Goal of Application to Depleted Uranium Penetrator Catch Boxes

Victor F. Medina and Scott A. Waisner

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Environmental Laboratory

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Victor F. Medina, Scott Waisner

*U.S. Army Engineer Research and Development Center*
*Environmental Laboratory*
*3909 Halls Ferry Road*
*Vicksburg, MS 39180-6199*

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# Abstract

Depleted uranium (DU) is used in three penetrator munitions by the U.S. Army, a 25-mm round (M242), 105-mm antitank rounds (M900, M774, M833), and 120-mm antitank rounds (M829, M829A1, M829A2). The last two of these munitions are frequently fired into large catch boxes at two proving grounds – Yuma Proving Ground near Yuma, AZ and the Aberdeen Proving Ground, MD. Gamma radiation surveys indicate that during penetrator impact DU ejecta in particulate material are deposited around catch boxes.

A scaled version of the catch box was constructed using SACON® concrete blocks and construction grade sand. Testing consisted of firing a three-shot salvo from a 50-caliber, Barrett Rifle using standard ball ammunition. Both high-speed Phantom and digital video cameras were used to capture ejecta images during the impact. Ejected sand settled on the capture tarp, where it was collected after shots.

Results indicated that use of water misters did not substantially reduce ejecta compared to untreated sand. The direct addition of water had confusing results. In some cases, directly irrigating the sand substantially reduced ejecta, but in other cases, it actually seemed to increase ejecta. A geotechnical slump study determined that 4% was the maximum amount of water that could be added to the sand without "strengthening" it. Testing with the 4% water addition produced consistent results, with 97% reduction of sand ejecta from untreated sand. In addition, efforts to intentionally compact the sand bed resulted, as expected, in large increases of sand ejecta.

The next phase of testing focused on the use of two dust palliatives, Durasoil® and TOPEIN-S®. The 1.25% Durasoil® worked as well as water and retained its effective performance after 11 days. When first applied, TOPEIN-S® worked well; however, after 1 month of weathering, it appeared that TOPEIN-S® behaved similarly as when too much water was added or when the bed was compacted.

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# Preface

This report investigates methods to reduce sand ejecta from projectile impact. This work was part of a project funded by the Army Range Technology Program (ARTP), which focused on the management of depleted uranium at test centers and proving grounds operated by the U.S. Army.

Dr. Victor F. Medina and Scott Waisner, both of the Environmental Engineering Branch (EP-E), Environmental Laboratory (EL), U.S. Army Engineer Research and Development Center (ERDC), prepared this report. Technical reviews were provided by Chris Griggs and Dr. Tony Bednar, ERDC-EL. Agnes Morrow, Milton Beverly (contractor, Environmental Research & Development, LLC), David Carter (student contractor, Alcorn State University), and Michael Jones (contractor, Applied Research Associates), all of ERDC-EL, provided valuable assistance during field studies. Joe Tom, Rick Magee, and Jamie Stevens, all of ERDC-GSL (Geotechnical and Structures Laboratory) provided shooting support. Dick Read of the U.S. Army Corps of Engineers Information Technology (ACE-IT) organization provided high-speed camera support.

This work was conducted under the general supervision of Andy Martin, Chief, EP-E, and Warren Lorentz , Chief, Environmental Processes and Engineering Division (EPED). Dr. Elizabeth Ferguson was the Technical Director.

At the time of publication of this report, Dr. Beth Fleming was Director of EL. COL Kevin J. Wilson was Commander of ERDC, and Dr. Jeffery P. Holland was the Director of ERDC.

# Acronyms

BBTS - Big Black Test Site

cm - centimeter(s)

DU - Depleted uranium

ft - foot (feet)

gal - gallon(s)

GP - Gun position

$G_s$ - specific gravity of sand

GSL - Geotechnical and Structures Laboratory

in - inch(es)

km - kilometer(s)

m - meter(s)

mm - millimeter(s)

MSDS - Material Safety Data Sheet

$N$ - open porosity

RSD - Relative Standard Deviation

s.g. - specific gravity

YPG - Yuma Proving Ground

YTC - Yuma Testing Center

U3/4Ti - An alloy used for most DU penetrators, containing ¾% titanium

USEPA - U.S. Environmental Protection Agency

$V$ - total volume

$w$ - moisture content

wt/wt - ratio of weight to weight

$W_s$ - weight of sand

$W_T$ - total weight

$W_w$ - weight of water

$\rho$ - density

$\rho_s$ - density of solids

# Unit Conversion Factors

| Multiply | By | To Obtain |
|---|---|---|
| cubic feet | 0.02831685 | cubic meters |
| degrees (angle) | 0.01745329 | radians |
| feet | 0.3048 | meters |
| gallons (U.S. liquid) | 3.785412 E-03 | cubic meters |
| inches | 0.0254 | meters |
| miles (U.S. statute) | 1,609.347 | meters |
| pounds (force) per square inch | 6.894757 | kilopascals |
| pounds (mass) | 0.45359237 | kilograms |
| square feet | 0.09290304 | square meters |
| yards | 0.9144 | meters |

# 1 Introduction

## Depleted uranium (DU) munitions

Both the United States and the United Kingdom initiated research to develop penetrators using depleted uranium (DU) in the 1960's to address concerns that improved armor development by the Soviet Union would render existing tungsten carbine penetrators ineffective (Global Security 2008). In 1973, an alloy was developed with DU and titanium, called the U3/4Ti alloy (because it included ¾% titanium as part of the formulation). This alloy allowed the penetrator to remain intact at high heat and velocity. By the mid 1970's DU penetrators were in service for the M68 105-mm antitank gun.

Depleted uranium munitions were first used in the 1991 Gulf War. The performance of these munitions in combat was considered highly successful. During one reported engagement, an M1A1 Abrams tank engaged three Iraqi T72 tanks. Each Iraqi tank was destroyed by single DU penetrator shots from the M1A1's 120-mm gun (Global Security 2008). These munitions have since been used in the Kosovo conflict in 1994 – 1999 and during Operation Iraqi Freedom in 2003 (Allen 2003, Graham-Rowe 2003). These subsequent conflicts have continued to show the remarkable effectiveness of DU munitions against armored vehicles.

The U.S. Army inventory of DU munitions includes a 25-mm round (M242), which is fired from the Bradley Combat Vehicle, M744 and M833 105-mm antitank rounds, which are fired in the M60 and M1 Abrams tanks, the M900 105-mm antitank rounds, developed for the 105-mm cannon found on the Bradley Fighting Vehicle, and 120-mm antitank rounds (M829, M829A1, M829A2) (Figure 1), used for the M1A1 tank (Figure 2).

## DU in the environment

### DU mobility

Mobility of uranium has been studied, but the actual mobility of uranium in the form of DU munitions is not well understood. Studies and modeling projects have been conducted related to the mobility of uranium and other related radioisotopes (Garten 1978, 1995; Garten and Trabalka 1983; Garten et al. 1978; Larson et al. 2004), but the applications have been for

Figure 1. An M829 Class DU penetrator at Yuma Proving Grounds.

Figure 2. M1A1 Abrams tank in a firing exercise at the Yakima Training Center.

mining waste or for sites of military production and training, in which the uranium or other isotopes were in much more mobile forms.

The Yuma Proving Ground (YPG) in Western Arizona (Cochran 1991; Ward and Stevens 1994) has been the most studied area in terms of DU fate and mobility. One test range (Gun Position (GP) 20) at YPG has been used for test firing of 25-mm rapid-fire cannons using DU munitions. The firing has been conducted in an impact area that affects a 1.6-km$^2$ wash. A series of environmental surveys were conducted between 1990 and 2003 in an effort to characterize the risks associated with the transport of DU from the firing ranges to the nearby river basins (Ebinger et al. 1990, 1994; Ebinger and Hansen 1996; Erikson et al. 1990, 1993; Levri 1997; Rael 1997; Army Environmental Ebinger and Hansen Policy Institute (AEPI) 1995). These studies concluded that the most likely means for DU migration off range is

by transport in sediment either as very small DU particles or as corrosion products adsorbed on the sediment. It is generally believed that migration of DU from this area is minimal, but studies to confirm this have been primarily small scale in nature. For example, small (1 x 1 m) simulated rainfall plots suggested that movement of DU alloys from penetrators due to rainfall would be minute (Ward and Stevens 1994). But this study did not account for corroded material or DU adsorbed on soil and sediment.

Johnson et al. (2006) used a distributed model to predict DU mobility at YPG. Their results suggested that DU movement would be expected to be very slow (on the order of centimeters to a few meters), even with very large storms. However, the model focused strictly on particles of metallic DU, and did not include soil adsorbed DU or dissolved DU.

### Oxidation of DU

The specific gravity (s.g.) of depleted uranium titanium alloys is on the order of 16. This high density makes it relatively difficult for particles to migrate any great distances, as found in the field and modeling studies discussed above. Although metallic uranium is essentially immobile, corrosion reactions with air and water can yield oxidized products, such as schoepite and metaschoepite [hydrated uranium (VI) oxides] (Chen and Yiacoumi 2002). Other minerals have also been identified from uranium corrosion in soil, including becquerelite, fourmuilerite, and sodium zippeite, among other trace phases (Buck et al. 2005). Figure 3 shows a rod with yellow (presumably schoepite) corrosion products.

These minerals have lower densities than metallic DU, for example, the s.g. of schoepite is on the order of 8. Furthermore, schoepite and other uranium minerals can dissolve to soluble U(VI), as $UO_2^{2+}$. These changes could enhance DU migration (Chen and Yiacoumi 2002; Sztajnkrycer and Otten 2004). Furthermore, complexation of $UO_2^{2+}$ with natural ligands (organic and inorganic) and absorption on soil will further alter mobility depending on how these secondary compounds interact with soil (Abdelouas et al. 1998; Elless and Lee 1998; Lenhart and Honeyman 1999).

Bednar et al. (2007) studied interactions of uranium oxides with organic material. Interestingly, adding organic material as humic acid to a low organic soil actually decreased soil adsorption. The study concluded that the humic acid actually competed with the uranium for adsorption sites on the soil, reducing uranium adsorption.

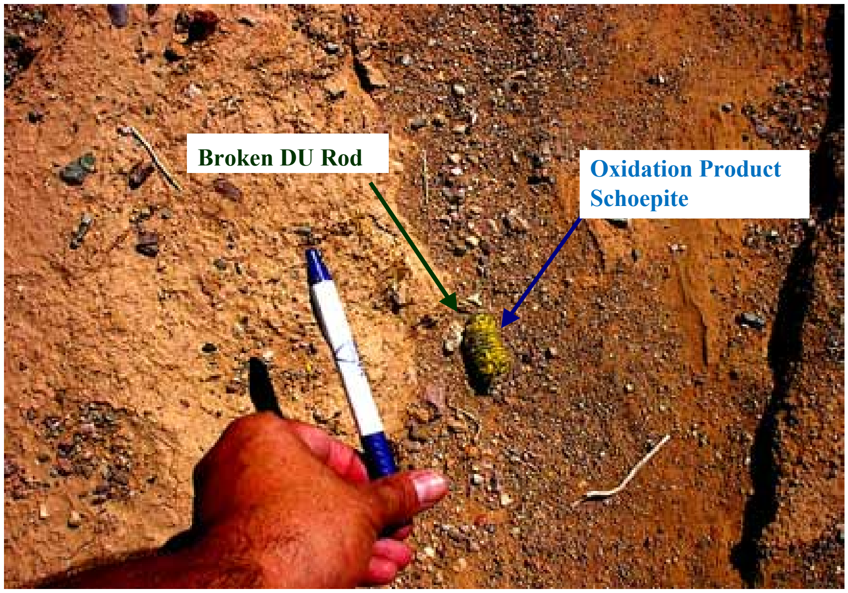



Figure 3. Broken DU rod with corrosion at the Firing Trench Area of YPG.

### Cleanup of DU

Larson et al. (2009) studied the removal of DU from contaminated soils and catch box sand. The study indicated that removal of metallic pieces larger than the sand grains (which most are) by screening methods was easily achieved, and that this removal could reliably remove greater than 50% of the DU, most catch box media, and soil. Removal of DU the size of soil or sand particles could be accomplished with other methods, but at this time, they do not appear to be cost-effective alternatives.

## DU contamination around the catch box at Yuma Proving Ground

DU penetrators are commonly fired into sand catch boxes (Figure 4) as part of test and training activities. Radiation surveys conducted as part of the Army Range Technology Program (ARTP) have shown that a measureable amount of DU escapes the catch box (Etheridge et al. 2009) (Figures 5 and 6), contaminating the soils surrounding them (Figure 7). Some of the DU was clearly from runoff, particularly that found at the toe of the sand bed. However, DU material on the sides of the catch box was likely deposited by ejecta during projectile impact or by wind erosion, although some was apparently spilled from a sand change-out operation conducted in the past. This project focused on evaluation of ejecta during projectile impact.


Figure 4. The catch box at Yuma Proving Ground.

Figure 5. Area adjacent to catch box. Blue lines were used to guide gamma radiation survey traverses in the vicinity of the box.


Figure 6. Radiation survey conducted by Mississippi State University using a push cart system (Etheridge et al. 2009).

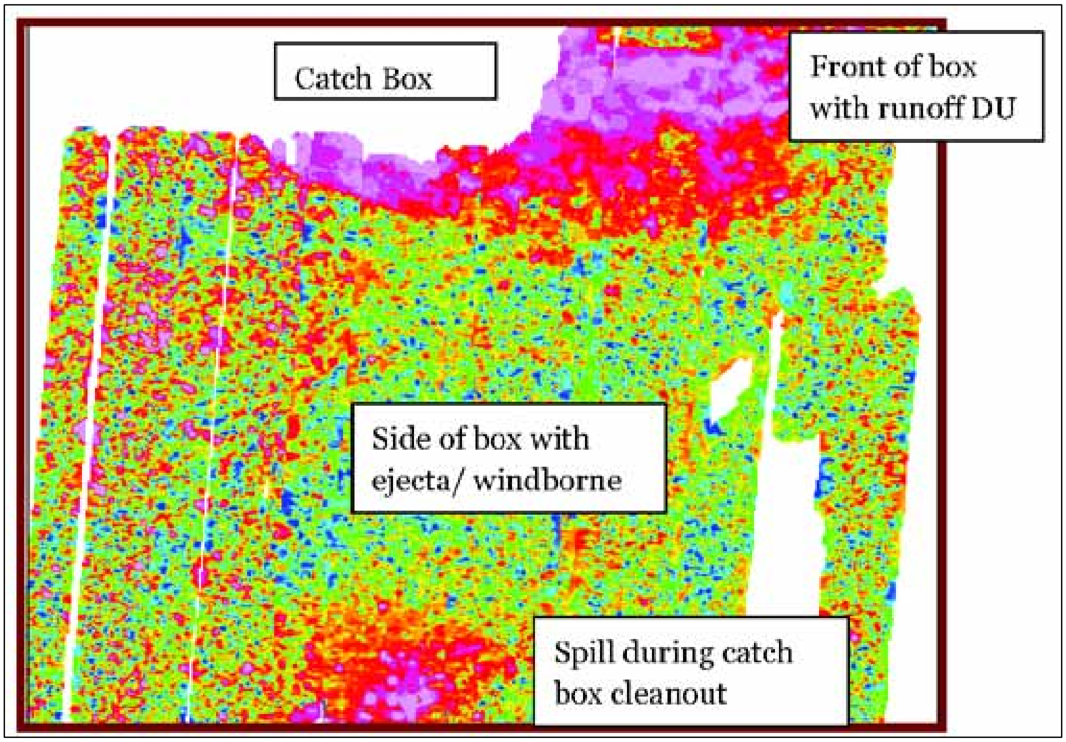



Figure 7. Radiation survey in the vicinity of the catch box. Blue and green indicate no detection. Pink and red are gamma-emitting radionuclide detections associated with daughter products of DU.

## Literature background in projectile impact in granular media

Previous studies have investigated the various effects of the impact of solid penetrators in beds of granular media. Hou et al. (2005) studied projectile impact in loose granular beds with fast video photography. They derived mathematical descriptions for penetration depth based on penetrator velocity and characteristics of the granular media. Ormo et al. (2006) studied cratering associated with aquatic impacts. Borg and Vogler (2008) conducted mesoscale studies of penetrators in sand beds with the goal of understanding grain level dynamics, and concluded that changing grain size and differences in fracture strength of the granular media can greatly affect penetration depth of the projectile. Addiss et al. (2009) combined experimental work with a finite element model to investigate the effect that long rod penetrators have on granular beds throughout the impact process.

# 2 Materials and Methods

## Overview

In order to evaluate treatments to reduce ejecta from DU projectile catch boxes, a simulated catch box test area was prepared at the Big Black Test Site (BBTS), which is located near Vicksburg, Mississippi. Penetrator impact was modeled by firing a 50-caliber bullet into the sand-filled simulated catch box. Effect on ejecta was measured two ways – by filming the effects of the impact and by recovering sand on a capture tarp. While bullet impact does not have a direct scalable relationship with a penetrator impact, it would allow for comparative effects of treatments at a much lower cost than full-scale studies.

## Area chosen for study

The study team coordinated site selection and site maintenance with the manager of the BBTS, Larry Garrett. An isolated area at the north end of the BBTS was chosen as the testing area (Figure 8). The area behind the test area had more than 2 miles (3.2 km) of undeveloped woodland in the unlikely event of a missed shot (Figure 9).

Figure 8. Test area prior to development.


Figure 9. Aerial view of test firing area showing 2 miles (3.2 km) of undeveloped woodland north of site. The yellow tab is the test site. The firing direction was due north.

## Simulated catch box

A simulated small-scale catch box was constructed based on the dimensions of the full-scale catch box provided by Aberdeen Proving Ground (see Appendix A). Catch box size was based on the ratio of the impact energy per cross-sectional area of the 50-caliber bullet versus that of the 120-mm projectile (Appendix A). The simulated catch box had the following dimensions: width: 3.4 ft (1.0 m), length: 6.9 ft (2.1 m), height: 3.5 ft (1.1 m), open angle: 27°. The box was constructed from SACON® concrete blocks (Figure 10), a special concrete block developed by the U.S. Army Engineer Research and Development Center (ERDC) Geotechnical and Structures Laboratory (GSL). The SACON® blocks are designed to prevent splintering and spalling if impacted by small arms fire. Figure 11 depicts the completed simulated catch box.

## Layout of firing area

Figure 12 is a schematic of the firing area layout. A table-mounted rifle was located 150 ft (45.7 m) from the simulated catch box. The test area was covered with a black plastic tarp measuring 40 x 40 ft (12.2 x 12.2 m). The tarp was divided into 16 sectors. The sectors were created by dividing the

Figure 10. SACON® blocks used to create simulated catch box floor.

Figure 11. Completed simulated catch box.

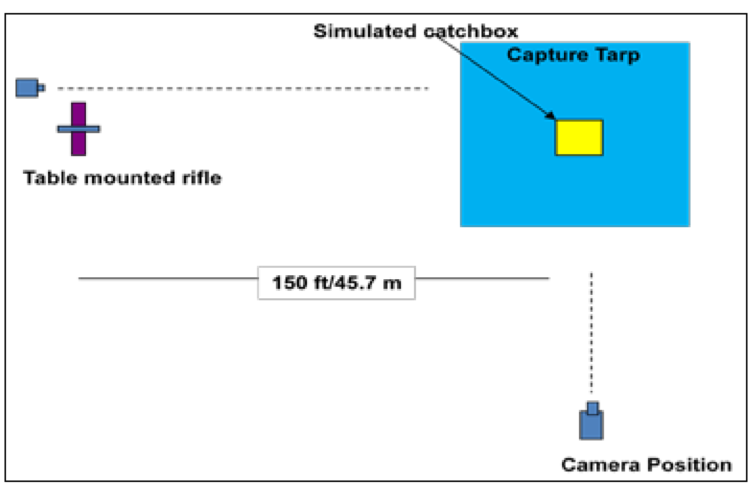



Figure 12. Schematic of firing area location.

tarp into four quadrants and three concentric circles at 5, 10, and 15 ft (1.52, 3.05, 4.57 m) from the point of impact. The final four sectors consisted of the remaining area from each of the quadrants outside the 15-ft circle. Figure 13 shows the catch box with the sectors marked on the plastic tarp. Camera positions were set up directly in front of the box and on the side, at 150-ft (45.7-m) distances.

Figure 13. Catch box with sectors on the plastic tarp.

## 50-caliber rifle and ammunition

A 50-caliber Barrett model 99 rifle was used for this project (Figure 14). This is a model that is commercially available in the United States. The rifle has a barrel length of 32 in. (0.81 m), overall length of 50 in. (1.27 m), and weighs 25 lb (11.4 kg). A Leupold 3-9 VariX II telescopic sight was attached to the rifle and used to sight the target. The rifle was mounted on a custom-made stand, which was placed on a steel table to provide a highly stable firing platform.

The original goal was to fire 50-caliber M903 SLAP (saboted light armor penetrator) rounds, which, like the DU penetrator, are saboted to increase their in-flight velocity (Department of the Army (DOA) 1994), but the rounds were not available. Two types of 50-caliber ammunition that were commercially available were used in this study: (1) lead ball (M33 ball) and (2) armor piercing (machine hardened steel, M2 armor piercing) (DOA 1994) (Figure 15). There was no noticeable difference in ejecta during

Figure 14. 50-caliber Barrett Model 99 rifle at firing point.


Figure 15. Fired M2 50-caliber round.

some piloting shots; therefore the lead ball ammunition was used because it was somewhat less expensive than the armor-piercing ammunition. The mass of M33 lead ball is typically 660 to 662 grains (42.9 to 43.0 g). Previous testing by GSL indicated that the velocity of this ammunition when fired from this rifle was 2930 fps at 50 yd.

All firing was conducted by ERDC personnel who are registered with the ERDC Security Office as personnel allowed to use firearms for research purposes. Shooters included Joe Tom, Jamie Stevens, and Ricky Magee, all GSL. A project-specific safety plan was produced (Appendix B).

## Cameras

Two Phantom high-speed digital video cameras (Figure 16) were used to record the impact of multiple test shots. The cameras captured video at a rate of 1000 frames per second and a resolution of 1024 x 1024. The cameras were automatically started by an acoustic trigger activated by the sound of the rifle fire and recorded a total of two seconds of video. Oscar Reihsmann and Dick Read of U.S. Army Corps of Engineers Information Technology (ACE-IT) organization served as the camera operators for the project. In addition, the ERDC Environmental Laboratory (EL) team also recorded the test shots with two standard-definition digital video cameras to capture a wider view of the tests (Figure 17) at normal speed. All cameras were mounted on tripods.

Figure 16. A tripod-mounted, high-speed Phantom camera.

Figure 17. Set-up of Phantom and digital video cameras.

Two 8-x 8-ft (2.44-x 2.44-m) reference walls with black plastic coverings and a 1-ft grid were set up on the far side of the catch box across from the camera positions to allow the ejected sand to stand out better during filming. Another 2-ft-(0.61-m-) diameter circular black camera target was set up above the back of the catch box. Two reference poles extending 6 ft (1.8 m) above the catch box were placed in the rear of the catch box to allow better estimation of ejecta height.

## Misting system

A water misting system (Figure 18) was constructed to cover the catch box with a blanket of mist over the impact surface during test shots. The system consisted of polypropylene tubing and misting nozzles attached to a frame constructed of aluminum tubing. The frame was designed to hold the nozzles in a plane parallel to and at a distance approximately 4 ft above the surface of the sand. Water was delivered through ⅜-in. (1.27-cm) outside diameter (OD) x ¼-in. (0.635-cm) inside diameter (ID) ( polypropylene tubing joined together by acetal-plastic Speedfit® push-to-connect connectors. Water was pushed from stainless steel tanks pressurized to 70 psi by a compressed-gas cylinder of nitrogen. Mist was created by mini-mist nozzles (McMaster Carr 3178K82, Figure 19) with a full-cone spray pattern and an 80° spray angle. The misting system contained 18 nozzles evenly distributed over the surface area of the sand. Each nozzle delivered approximately 1.7-gal/hr of mist for a total flow rate of approximately 30.6 gal/hr of water.

Figure 18. Misting system.

Figure 19. Mist spray nozzle.

## Standard experimental procedure

A single shooting event consisted of three consecutive shots from the 50-caliber rifle (Figure 20). The camera systems filmed the ejecta associated with the three shots. After the three shots, a team collected sand from the collection tarp (Figure 21) by sweeping the sand from each sector (defined in section "Layout of firing area") into individual piles and collecting each pile into preweighed plastic bags. The bed was smoothed back to the 27° slope between each individual shot. Bullets were dug out and recovered after each day's shooting to avoid round-on-round impacts, which would result in skewed results.

Figure 20. Impact of 50-caliber projectile into catch box from firing position.

Figure 21. Collecting sand after a set of three shots.

After transport back to the laboratory, the collected sand was dried in an oven at 105 °C and weighed on an analytical balance with an accuracy of 0.1 g. Each test was replicated three to five times.

## Treatments

The following conditions were tested:

- No treatment
- Water misting
- Direct water irrigation – exact water content not controlled
- 4% direct water irrigation
  - Loosened by drill-operated auger
  - Compacted with a board
- 1.25% Durasoil® – a dust palliative produced by Soil Works, LLC. Appendix C is a Material Safety Data Sheet (MSDS) for Durasoil®. Soil Works, LLC provides the following product description for Durasoil®:

  > Durasoil® is distinctively crystal clear, odorless and is applied neat and simple, without the need for water dilution. This technologically advanced fluid does not cure, allowing for immediate use upon its application. Furthermore, Durasoil® has the unique ability to be reworked and still maintain its dust controlling properties. Any equipment capable of spraying water can safely be used to apply Durasoil®, without any mess or damage to the equipment. Even in freezing and wet conditions, Durasoil® can still be applied regardless of weather conditions or season.

Durasoil® can be applied to any soil or aggregate and effectively suppress dust all year round.

- 2.5% TOPEIN S® – a dust palliative, moisture sealant, and soil treatment fixative prepared by emulsifying tall oil pitch (Figure 22), which is a plant resinous material commonly found in paper mill operations. The specialty emulsion is produced by Encapco Technologies, LLC of Napa, CA, which holds a patent for the technology (Jones et al. 1997); however, it is produced and sold by a number of companies. A material safety data sheet for TOPEIN S® is provided in Appendix D. Both TOPEIN S® and TOPEIN C® (which also contains asphalic resins) have been tested by ERDC for stabilization of soils and radionuclides in soils (Rottero et al. 2005; Larson et al. 2004) and on building surfaces (McGehee et al. 2007).


Figure 22. Tall oil pitch.

## Calculations

### Statistical significance

Statistical significance was determined using ANOVA with a 95% confidence interval.

### Inertia about point of impact

The change of inertia of the sand ejected from the catchbox was calculated by making the following two assumptions:

1. All the sand ejected from the catchbox originated from the point of impact.

2. The total mass of sand recovered from each sector was located at the center of gravity of that sector's area.

Based on this simplification, the initial inertia of the ejected sand is zero, and the final inertia is the mass multiplied by the square of the radius of the sector's center of mass from the point of impact.

The center of gravity for each sector was based on the area of that sector lying outside the catch box. The center of gravity for the sectors lying outside the 15-ft circle was calculated based on the area of that quadrant between the 15-ft and 20-ft circles. This simplification was justified by the fact that very little sand was recovered beyond 20 ft from the point of impact. The sectors of the test area are depicted in Figure 23 with labels, and the calculated center of gravity for each sector is listed in Table 1.

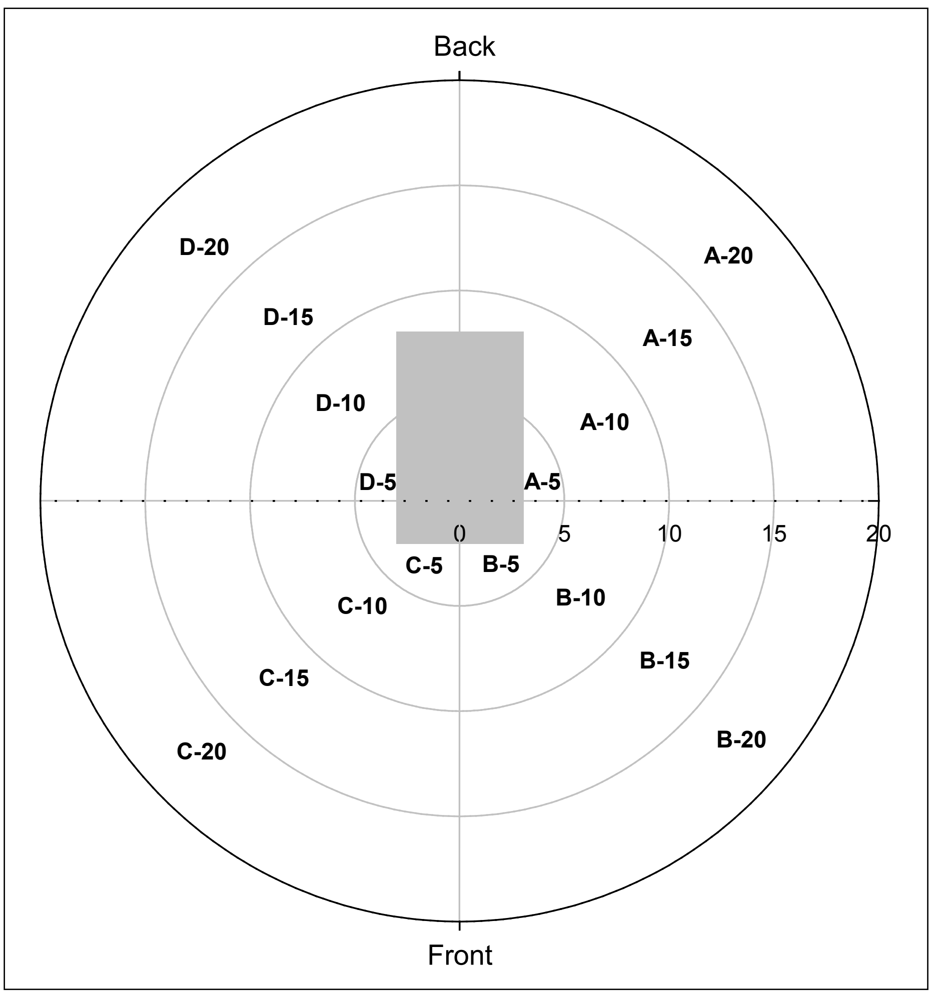



Figure 23. Diagram of test site sectors.

Table 1. Area and center of gravity for test area sectors.

| Sector | Area (sq ft) | x (ft) | y (ft) | r (ft) |
|---|---|---|---|---|
| A-5 | 5.59 | 3.816 | 1.550 | 4.119 |
| A-10 | 51.95 | 6.023 | 5.545 | 8.187 |
| A-15 | 98.17 | 8.061 | 8.061 | 11.404 |
| A-20 | 137.44 | 11.217 | 11.217 | 15.863 |
| B-5 | 12.13 | 2.507 | -2.661 | 3.656 |
| B-10 | 14.73 | 4.951 | -4.951 | 7.002 |
| B-15 | 98.17 | 8.061 | -8.061 | 11.404 |
| B-20 | 137.44 | 11.217 | -11.217 | 15.863 |
| C-5 | 12.13 | -2.507 | -2.661 | 3.656 |
| C-10 | 14.73 | -4.951 | -4.951 | 7.002 |
| C-15 | 98.17 | -8.061 | -8.061 | 11.404 |
| C-20 | 137.44 | -11.217 | -11.217 | 15.863 |
| D-5 | 5.59 | -3.816 | 1.550 | 4.119 |
| D-10 | 51.95 | -6.023 | 5.545 | 8.187 |
| D-15 | 98.17 | -8.061 | 8.061 | 11.404 |
| D-20 | 137.44 | -11.217 | 11.217 | 15.863 |

## Flooding and weather issues

The test area was periodically damaged by severe storms and flooding by the Big Black River (Figures 24 - 26), which resulted in delays in the shooting schedule. However, the team was able to make repairs and resume testing once the weather and flooding subsided.

Figure 24. Flooding at the BBTS, October 2009.

Figure 25. Storm and flood damage at the BBTS, January 2009.

Figure 26. Flood damage, November 2009.

# 3 Results and Discussion

## Pilot shots

Preliminary shots were conducted to gauge the magnitude of the sand ejection and to develop the experimental plan. The first three test shots into the sand box are depicted in Figure 27, and they showed that the majority of the ejected sand was likely to land within a 10-ft (3-m) radius of the point of impact. Excavation of the bullets indicated that they penetrated approximately 18 to 24 in. (45.7 to 70 cm) into the sand. The phenomenon of bullet skipping, where bullets ricochet off the berm material, was not observed during this study.

Figure 27. Preliminary test shots.

## Water studies

### Initial studies evaluating misting and water addition

The first set of testing compared ejecta from various conditions, including no treatment, use of the mist curtain, and moderate pre-wetting of the catch box sand by direct irrigation of water. Figure 28 summarizes the results for these shots, showing the total mass of sand ejected for each set of shots and the average and standard deviation of each test condition. For the control (no treatment), the average mass of sand ejected was 1091 g, and there was a 36% relative standard deviation (RSD). Using a mist curtain, the average sand recovered was 1008 g with an RSD of 2%. A mist curtain may reduce the migration of dust during shooting, but dust could not be discerned from the mist itself during the tests. Adding water directly on the sand bed produced an average mass of sand ejected of 983 g and an RSD of 87%. An analysis of variance test (ANOVA) indicated that there was not a statistically significant difference ($\alpha = 0.5$) between the means of the various treatments. However, a mist curtain did reduce the variability, and direct irrigation of water to the sand increased the variability of ejecta between sets of shots.

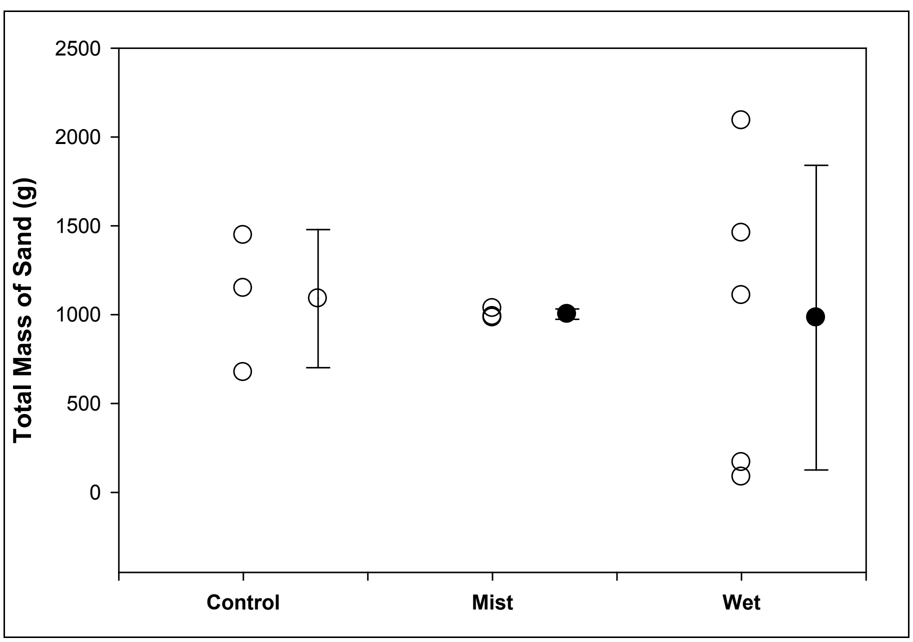



Figure 28. Mass of sand ejected from control and water treatments.

Figure 29 shows the median results of the total mass of ejected sand for the three treatments. Each dot represents the mass of sand recovered in each sector and is located at the center of gravity for that sector. The size of the

dot is proportional to the mass of sand recovered in the sector. These diagrams illustrate the distribution of the sand ejected from the catch box. Obviously, the direction of sand deposition was influenced by differences in wind speed and direction, which inevitably occurred during the testing.

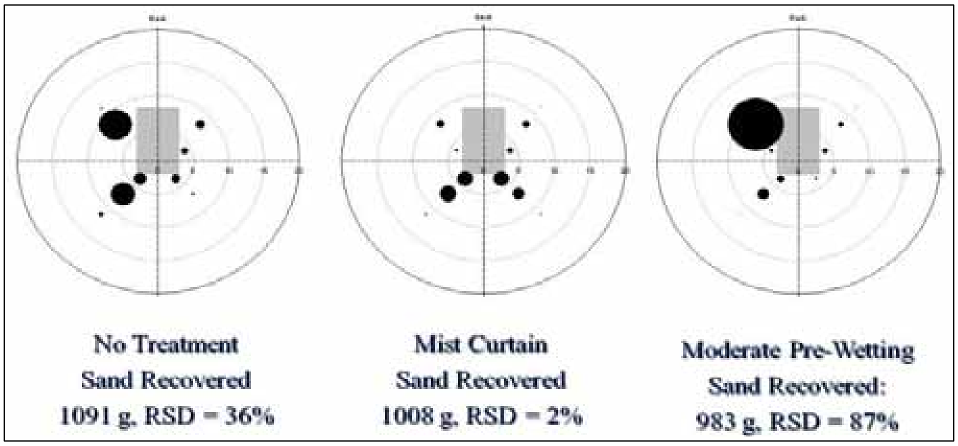



Figure 29. Target diagrams of median result for no treatment, mist curtain, and moderate pre-wetting of the sand bed.

Using the change of inertia in the ejected sand about the point of impact to measure treatment effectiveness was also investigated. The results of these calculations are illustrated in Figure 30. The RSD values for the control, mist, and wet condition were 25%, 24%, and 86%, respectively. Measuring the change in inertia about the point of impact did not appear to consistently reduce the relative variability of the results when compared to the use of total mass ejected. Therefore, the total mass of sand ejected was used to compare results throughout the tests.

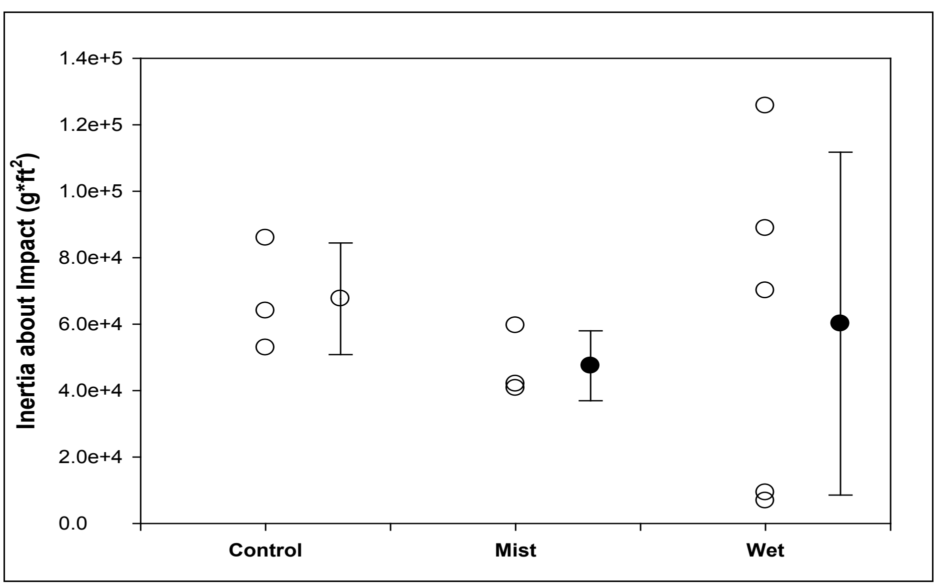



Figure 30. Change in inertia of ejected sand about the point of impact.

### Effect of controlled water addition and packing

Based on the results of initial tests with direct irrigation with water, it was clear that simply adding water was not consistently effective at reducing the mass of sand ejected from the catch box. In reviewing the video (the videos were reviewed and notes taken during the process) and data of the shots with wet sand, it became apparent that the mass of sand ejected decreased with each successive shot into the sand on an individual test day. Data for the five sets of shots are provided in Table 2. These results suggest that direct water addition can be effective, but that other factors (e.g., compaction, which had not been measured) played a role in its effectiveness.

Table 2. Mass of sand ejected from tests with direct irrigation of sand.

| Test | Date | Total Mass (g) |
|---|---|---|
| Wet 1 | 10/8/2008 | 2092 |
| Wet 2 | 10/8/2008 | 1459 |
| Wet 3 | 10/8/2008 | 169 |
| Wet 4 | 10/22/2008 | 1109 |
| Wet 5 | 10/22/2008 | 87 |

In preparation for further field tests, laboratory testing was conducted to estimate the level of water content in the sand that can produce the loosest sand condition. Tests were conducted by adding a known mass of sand and water to a jar and thoroughly mixing the contents by manually agitating the jar. A sample of the resulting wet sand was then carefully spooned into a graduated cylinder and the mass and volume of the sand were recorded. The sand was then compacted in the graduated cylinder by manually tamping the sand, and the new volume was recorded. This procedure was repeated at several different moisture contents.

Using the results from these procedures and the specific gravity of the sand, the moisture content, open porosity, and bulk density were calculated according to Equations 1 and 4, respectively, and the results are presented in Figure 31.

$$w = \frac{W_w}{W_T} \tag{1}$$

where:

$w$ = moisture content
$W_w$ = weight of water
$W_T$ = total weight

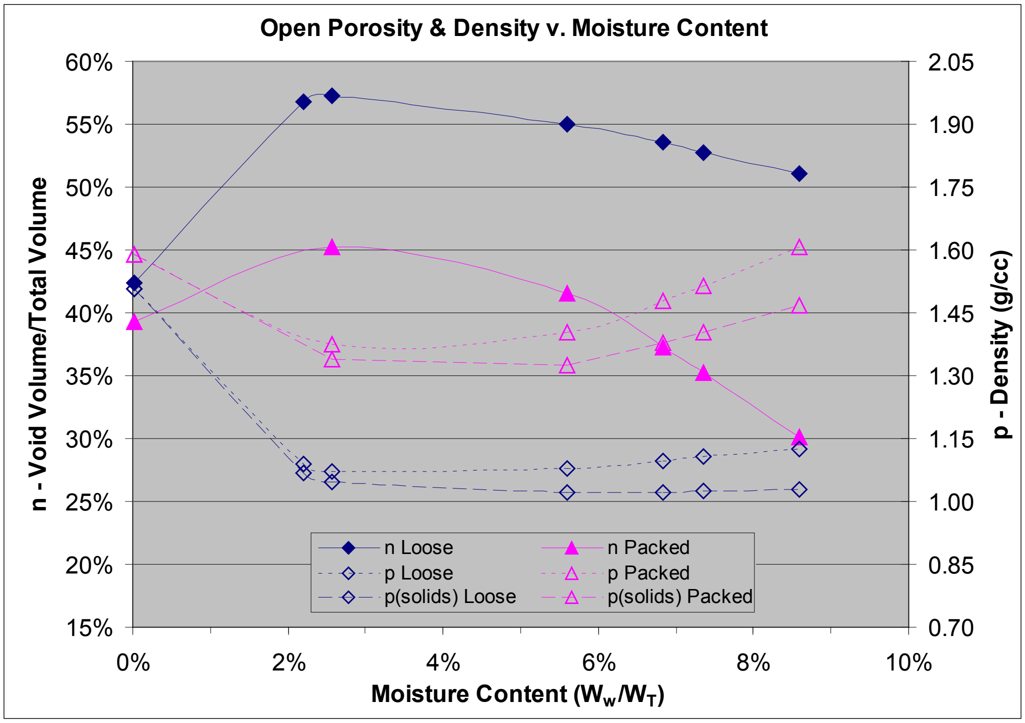



Figure 31. Open porosity and density vs. moisture content.

$$n = \frac{V - W_w - \frac{W_s}{G_s}}{V} \tag{2}$$

where:

$n$ = open porosity
$V$ = total volume
$W_w$ = weight of water
$W_s$ = weight of sand
$G_s$ = specific gravity of sand

$$\rho = \frac{W_T}{V} \tag{3}$$

where:

$\rho$ = density
$W_T$ = total weight
$V$ = total volume

$$\rho_s = \frac{W_T - W_w}{V} \quad (4)$$

where:

$\rho s$ = density of solids
$W_T$ = total weight
$W_w$= weight of water
$V$ = total volume

The tests show that open porosity is at a maximum at approximately 3% moisture content. This turns out to be true whether the soil is fluffed (loose) or packed. This appears to be the minimum level of moisture necessary to cause weak binding of the soil particles by surface tension of the water. Given this information, it was concluded that if the moisture content of the first 4 to 6 in. of sand near the impact point was maintained in the range of 2% to 6%, suppression of dust and ejection of sand from the catch box would be maximized. The moisture content of air-dried soil appeared to be below 0.5%.

To test the hypothesis, four additional sets of shots were conducted. The first three sets were conducted with wet sand that had been loosened with a hand-drill-operated, 6-in.-diameter auger. The sand was loosened over an area spanning an approximate radius of 18 in. from the impact point for the tests. The fourth set of shots was conducted after manual compaction of the sand around the impact point with the back of a shovel.

The results from these four shots are presented in Figure 32 as target diagrams of the median of the first three sets of shots and the one set of shots into compacted sand. The results were dramatically different. Loosening the sand resulted in a mean mass of sand ejected of 37 g, which was a 97% reduction from the mean of 1091 g seen in the control condition (see Figure 29). Conversely, compacting the wet sand bed resulted in 2341 g of sand ejected, which is more than double the mean of the control and nearly 15 times the mean from the loose bed of sand.

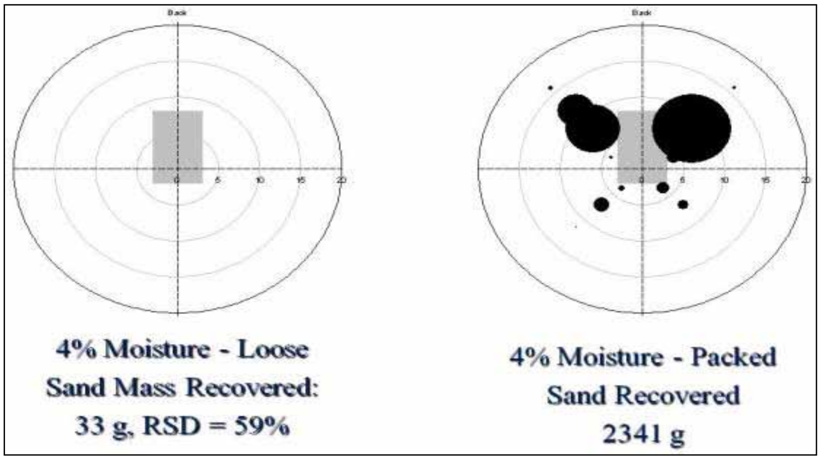



Figure 32. Application of 4% moisture (by weight) to sand, comparison of packed and loose bed surface.

The original goal of adding water was to increase the effective mass of the sand grains, which would require more energy to eject them. However, the addition of water may also increase the cohesion of the sand, which can allow the sand to maintain a greater porosity. The addition of too much water results in filling of pore spaces, which may restrict the release of expanding gases in the sand from the impact and transfer more kinetic energy to the sand. After watching the video from these studies, it was theorized that the ejection of sand was controlled by kinetic energy and its dissipation. In both compacted and saturated sand, the energy of the projectile is being transferred through the sand by direct particle-to-particle contact and air pressure. This model of thinking is supported by the results of Addiss et al. (2009), who found wave-like energy propagations in sand beds impacted by long penetrators. Loosening of the sand results in a reduction of the particle-to-particle interaction and facilitates the release of expanding gas in the sand.

## Dust palliatives

Results from “Controlled Water Addition and Packing” indicated that direct water addition, if properly applied, could be an effective means for reducing ejecta. However, maintaining the water content in the optimum range of 2 to 6% could be very difficult because of weather conditions such as rain and heat. In particular the dry heat at YPG would likely require the frequent addition of water during testing, which would be burdensome. To circumvent this issue, dust palliatives were investigated as a means of providing sustained similar treatment effects. Two palliatives were chosen for testing, Durasoil® and TOPEIN S®, which are described below.

### Durasoil®

Prior to field evaluation, laboratory investigations were conducted to determine the optimum level of Durasoil® addition required to maximize the open porosity of the sand. The procedures were the same as those described previously on page 23. The results of laboratory tests with Durasoil® are presented in Figure 33. From these results, it was determined that addition of 1.25% Durasoil® content would maximize the open porosity of the sand.

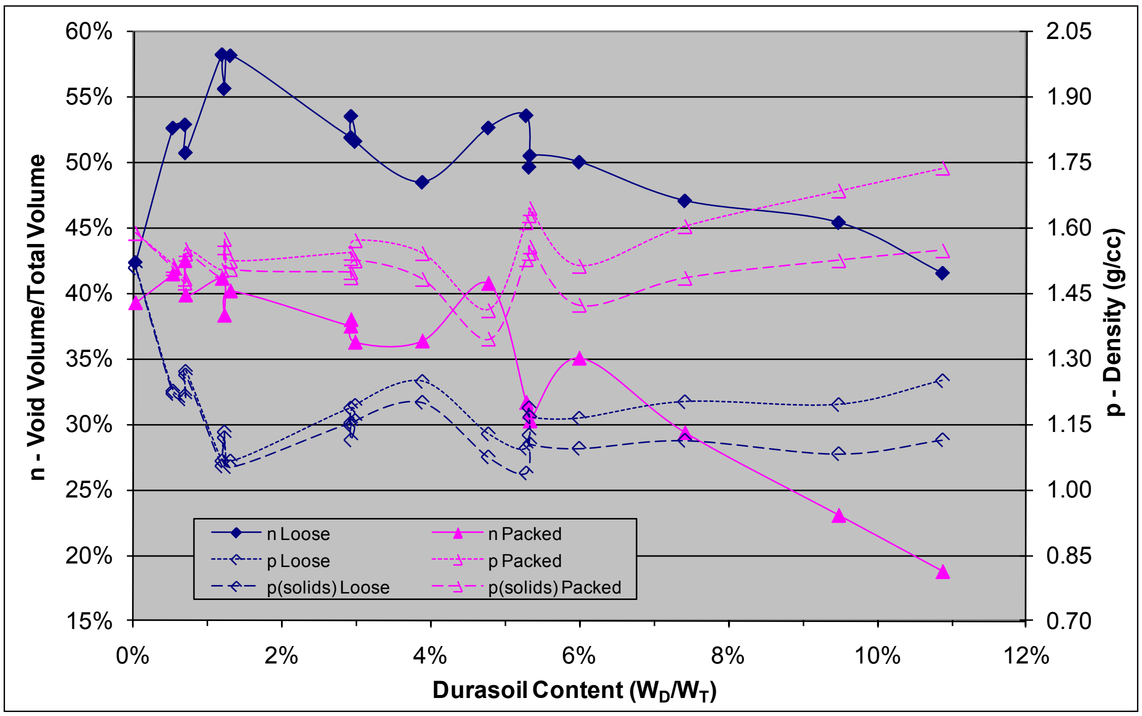
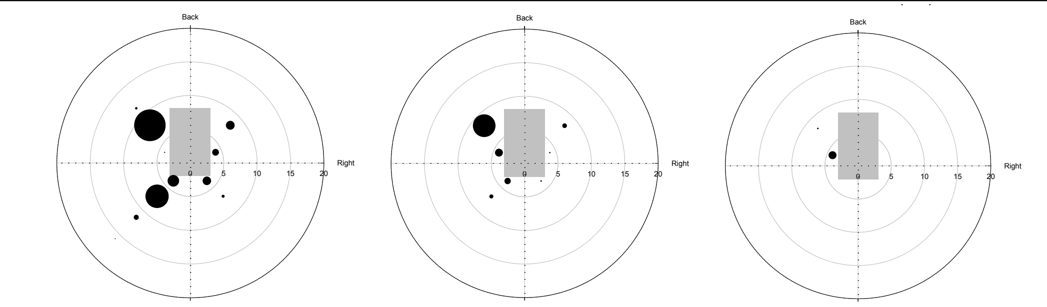



Figure 33. Open porosity and density vs. Durasoil content.

For field tests with Durasoil®, approximately 18 $ft^3$ of sand was dug out of the catch box from the impact point and treated with 1.25% Durasoil® by weight. Durasoil® was applied to the sand in a cement mixer and allowed to thoroughly distribute through the sand. The sand was then placed back in the catch box for testing. Four sets of test shots into the Durasoil® treated sand were conducted. These tests resulted in a mean mass of sand ejected of 354 g with an RSD of 98%, which is a statistically significant 68% reduction from the untreated control condition (mean = 1091 g, RSD = 36%).

After 11 weeks of weathering of the Durasoil® treated sand, three more sets of test shots were conducted. The temperatures and precipitation were highly variable during this weathering period, which lasted from November

to February. These test shots resulted in a mean mass of sand ejected of 115 g with an RSD of 48% and showed that Durasoil® is capable of performing well after significant weathering. In fact, the 89% reduction compared to the untreated sand was actually greater than the freshly added Durasoil® sand. The median results of the Durasoil® shots are compared with the control condition in Figure 34.




No Treatment
Sand Recovered
1091 g, RSD = 36%

1.25% Durasoil
Sand Recovered
354g, RSD = 98%

1.25% Durasoil + 11 weeks
Sand Recovered
115 g, RSD = 48%

Figure 34. Target diagrams comparing no treatment, 1.25% Durasoil, and 1.25% Durasoil after 11 weeks of weathering.

### TOPEIN S®

Prior to field evaluation, laboratory testing was conducted to determine the optimum level of TOPEIN S® addition required to maximize the open porosity of the sand. The procedures were the same as those described previously on page 23. The results of laboratory tests with TOPEIN S® are presented in Figure 35. It was noticed during testing that the dried TOPEIN S® solids had a much higher cohesive nature than the Durasoil® and water and tended to cause the sand to pack together whenever the mixture was shaken in a jar. It was determined from testing that the TOPEIN S® emulsion was 41% solids by weight and that 2.5% dry TOPEIN S® emulsion by weight on the sand was sufficient to create noticeable cohesion of the sand particles. Therefore, a 2.5% TOPEIN S® emulsion was used in the field evaluations.

In preparation for field evaluation with TOPEIN S®, sand treated with Durasoil® was removed from the catch box. Approximately 20 ft$^3$ of clean sand was treated with a 2.5% TOPEIN S® emulsion to weight of sand in a cement mixer. The treated sand was then placed back in the catch box at the impact point for the tests.

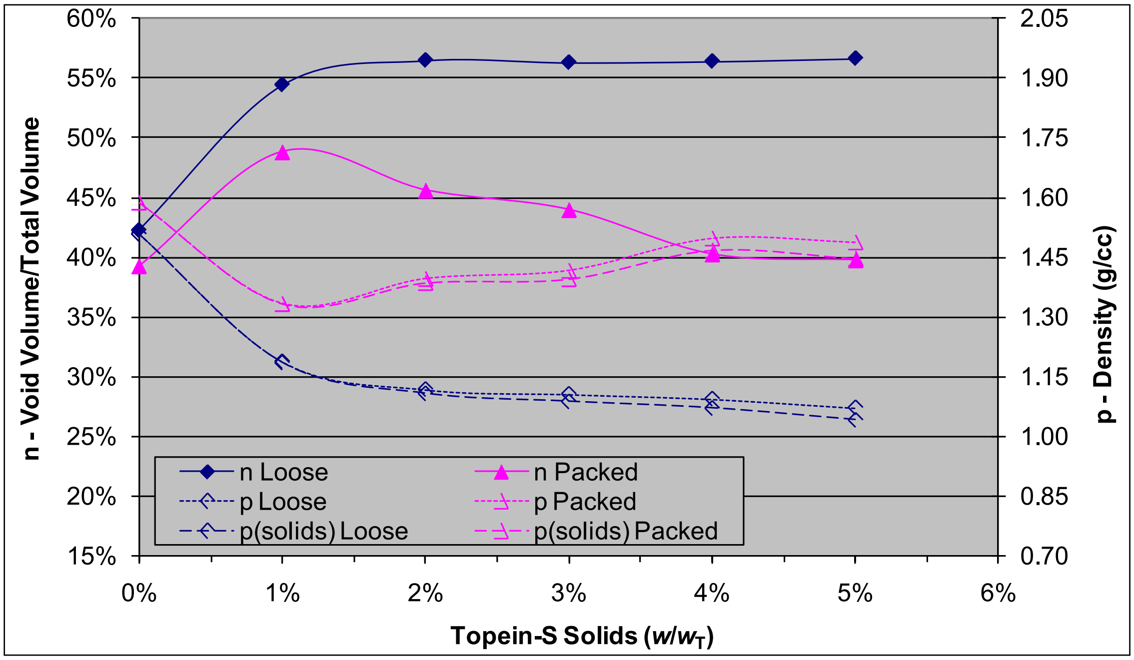



Figure 35. Open porosity and density vs. dry TOPEIN S® solids content.

Three sets of test shots were conducted the day after application of the TOPEIN S® and resulted in a mean mass of sand ejected from the catch box of 142 g with an RSD of 83%. After 1 month of weathering, three sets of test shots were again conducted on the TOPEIN S® treated sand to estimate its continued level of performance. These test shots resulted in a mean mass of sand ejected of 1801 g with an RSD of 52%. The initial shots showed a significant reduction of sand ejected compared to the control condition, but after one month of weathering, the TOPEIN S® appears to increase the mass of sand ejected when compared to the control. This comparison is illustrated in Figure 36.

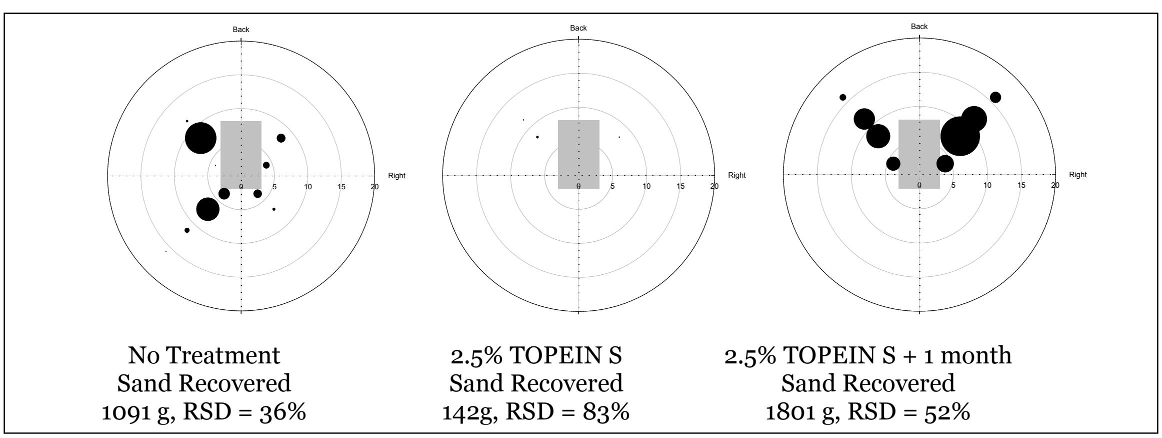



Figure 36. Target diagrams comparing no treatment, 2.5% TOPEIN S, and 2.5% TOPEIN S after 1 month of weathering.

## Summary

Figure 37 summarizes the results of the tests conducted in the study. Maintaining a water mist curtain over the catch box did not appear to provide any noticeable benefit toward reducing the ejection of sand from the catch box. A 4% water addition was very effective at reducing sand ejecta and appears to do so by maintaining the sand in a loose condition through the surface tension of water and sand particles. Unfortunately, maintaining specific moisture content in sand can be very difficult in the natural environment. The 1.25% Durasoil® was also very effective at reducing ejecta and maintained this effectiveness after 11 weeks of outdoor weathering. TOPEIN S® effectively reduced ejection of sand from the catch box 1 day after application, but it appears to exacerbate the problem after the emulsion dries significantly and becomes very tacky.

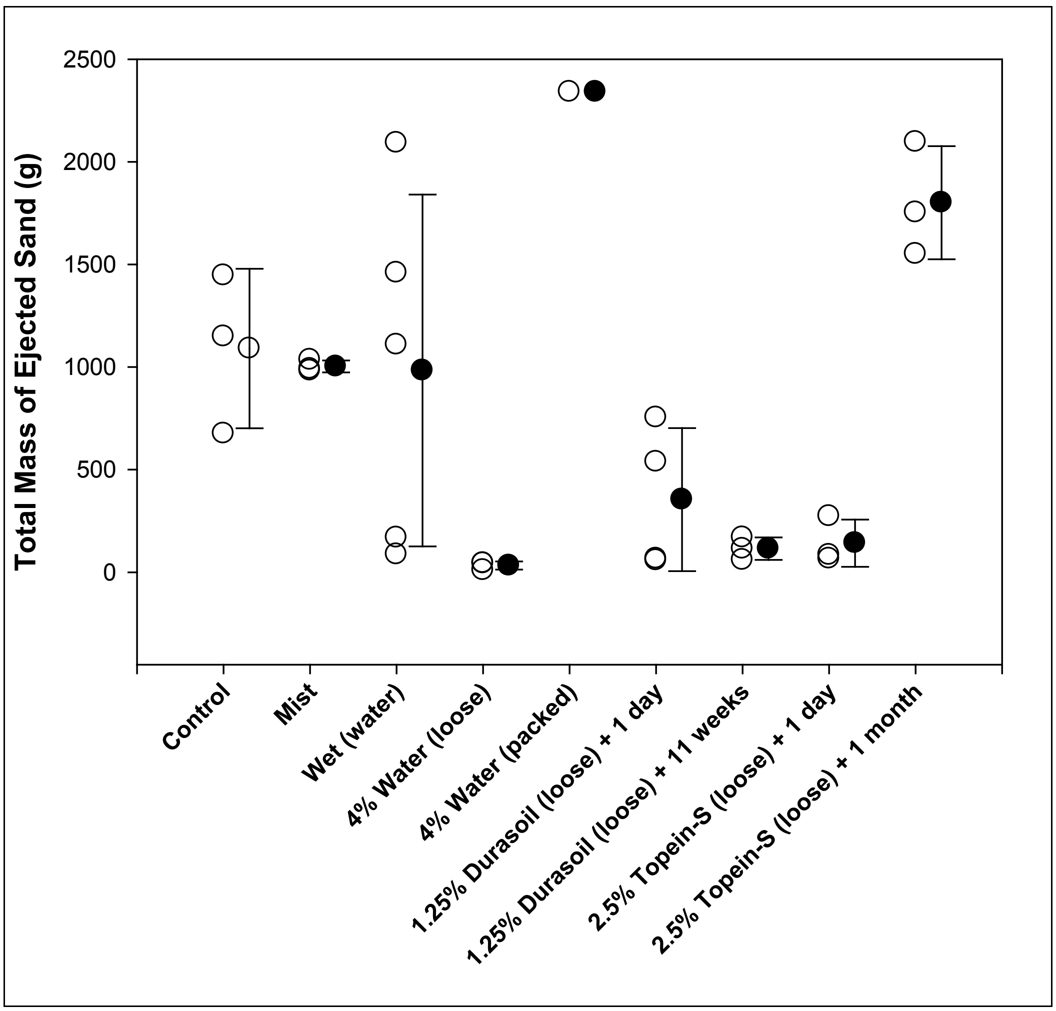



Figure 37. Summary of results.

Durasoil® and TOPEIN S® appear to work differently. It is likely that Durasoil® works similarly to water by holding the sand particles loosely together through surface tension between the fluid and the sand particles. The treated material is not sticky, and the grains do not appear to be strongly held together. TOPEIN S®, on the other hand, seems to work by creating a sticky film with cohesive strength increasing with weathering. As the cohesive strength increases, the sand appears to pack together and form clumps that are ejected out of the sand box.

Figure 38 is a time-lapsed photograph that visually illustrates the difference in sand ejection between untreated sand and sand treated with 1.25% Durasoil®. The total time span between the first and last frames is approximately 1/10 of a second.

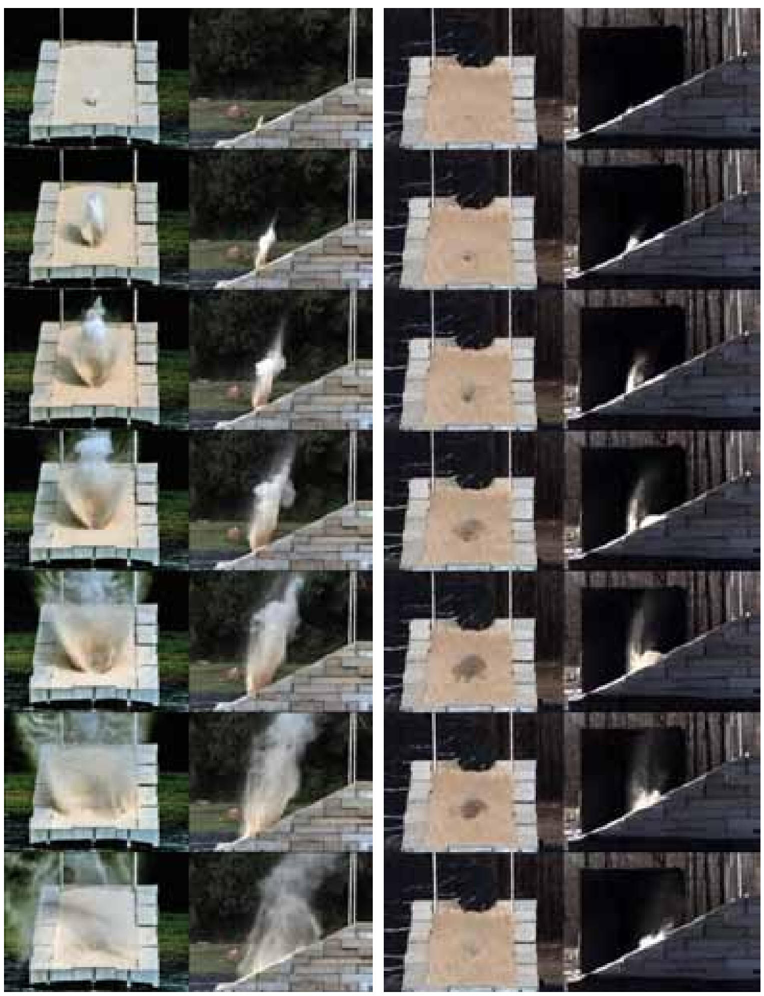


Figure 38. Control (left) vs. 1.25% Durasoil® treatment.

# 4 Proposed Full-scale Study

A full-scale study was developed and proposed at Yuma Proving Ground (YPG). This study was initially approved and a plan was developed for this application. However, the study was withdrawn due to changes in catch box management procedures, which may have resulted in costs so high as to make the project unaffordable. Should conditions change, the study plan provided in this document will make it possible to quickly implement a full-scale study.

## Full-scale study at Yuma Proving Ground

### Proposed plan

Appendix E contains the detailed plan for the full-scale study that is supported by the YPG Commander.

#### Assessment of Durasoil®

There is concern that using Durasoil® as an additive to catch box sand will change the waste status of the sand when disposal is necessary. Currently, sand is disposed of as a low-level radioactive waste. The concern is that an additive could result in the sand also being categorized as a hazardous waste, which would make the sand a mixed waste, which would increase disposal costs and severely limit potential disposal options.

The first step was to assess the potential chemical toxicity classification. The MSDS for Durasoil® was provided to the Radiation Safety Office at YPG, who forwarded a copy to the Radiation Safety Officer for the U.S. Army (Kelly Crooks, Army Joint Munitions Command). After review of the MSDS, it was determined that the Durasoil® had no chemicals of concern in terms of classifying the sand as hazardous.

The second concern was flammability. Durasoil® is an organic chemical mixture and can burn. An ignition test was performed on Durasoil® itself using an open-cup flash-point tester. Both the flash and fire point occurred at 190 °C (374F); however, when the flame was removed from the bottom of the cup, the burning Durasoil® could only sustain the heat necessary to burn for less than 2 minutes. This indicates that Durasoil® is unlikely to support sustained burning once an external heat source is removed.

Next, burn tests were conducted on Durasoil® applied to sand. One test evaluated 1.25% (w/w) Durasoil® evenly applied/mixed into the sand. The other test studied surface addition of Durasoil® to the sand. For both tests, a butane torch (approximately 2000 °C in air) was used to burn the sand. There was no open flame with the 1.25% Durasoil. There was an open flame with the surface application, but it died very quickly after removing the torch.

It was concluded that it would take sustained heat from a secondary source to maintain a flame on the surface of sand treated with Durasoil®. Because Durasoil® has a low volatility, it does not produce enough vapor to generate the heat necessary to continue burning. Due to lack of sufficient oxygen in the sand, especially at the depth that the projectile will be introduced, burning can only take place at the surface of the sand, where most of the heat is lost. Although it is possible that a flame could flash during full-scale impact, it has been demonstrated that it would die quickly. Furthermore, the combustion products listed for Durasoil® (carbon dioxide and carbon monoxide) are relatively benign for open-air release.

Videos of the flame test as well as the subsequent analysis were sent to the YPG Radiation Protection Office and forwarded to the Army Radiation Safety Officer. They concluded that the addition of Durasoil® to catch box sands would not cause an ignition of fire upon penetrator impact, nor would it result in the sand being categorized as a hazardous waste due to flammability (Appendix F).

### Sticky sand traps

Because the capture tarp concept used at the BBTS would not be practical for full-scale application, an easy-to-use sampler was developed that could be rapidly deployed. The concept of a “sticky trap” was developed as a sampling alternative. Sticky traps would be plastic bins with a sticky glue material that would capture impacting sand. The amount of sand and other particles captured could be quickly determined simply by weighing the trap before and after use. The glue could be chemically dissolved, allowing for chemical analysis of the particles to determine any captured uranium.

Preliminary testing was conducted at the simulated catch box at the BBTS. These studies indicated that the traps were very effective at capturing sand particles (Figures 39 - 41). Traps used in full-scale applications are easily adapted.

Figure 39. Sticky trap applied to the simulated catch box.

Figure 40. Sticky trap after firing with sand captured.

Figure 41. Sticky trap with sand captured and sealed for transport.

# 5 Conclusions

The following conclusions were determined from this study:

- Misting was not effective at reducing sand ejecta from a simulated catch box, presumably because the dust suppression force from the mist was much less than the energy of the sand ejecta.
- Direct water irrigation could be effective for sand ejecta if water content was high enough to hold sand grains together through surface tension between the water and sand and low enough to not significantly fill the pore spaces. For the sand used in the simulated catch box, this level was 2 to 6%, with a target of 4% chosen for experiments.
- Packing was also a critical factor. If the bed was intentionally compacted, the ejecta value was much greater. However, simple raking of the bed was enough to create looser conditions, which resulted in consistently low masses of ejecta recovered.
- TOPEIN S®, a dust palliative derived from emulsifying tall oil pitch with water, was not effective at reducing impact ejecta after minimal aging, presumably because it resulted in a cohesive force between sand grains that was too high, which resulted in clumps of sand and increased the ejected mass.
- Durasoil®, a dust palliative produced by SoilWorks®, was as effective as water in reducing sand ejecta. Durasoil® appears to provide a coating around each grain that creates a surface tension similar to water. This condition was maintained through 11 weeks of weathering. Effective performance was found by adding 1.25% Durasoil® to sand (wt/wt).

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# Appendix A: Scaling Calculations for the Simulated Catch Box

**M829A2 (120mm DU) Ballistics [1]**

| | | | | |
|---|---|---|---|---|
| Diameter | 0.8 | in | 2.032 | cm |
| Mass | 10.85 | lbm | 4.921 | kg |
| Velocity | 5512 | ft/s | 1680 | m/s |
| $K_1$ | 2559 | ft ton | 6946 | kJ |
| $A_1$ (front) | 0.503 | $in^2$ | 3.243 | $cm^2$ |
| $K_1/A_1$ | 5092 | | 2142 | $kJ/cm^2$ |

**YPG Catchbox for M829A2**

| | Reported | Calc. |
|---|---|---|
| Width (ft) | 47 | |
| Length (ft) | 95 | 83 |
| Height (ft) | 48 | 55 |
| Volume (cy) | 2500 | 3969 |
| Open angle (°) | 30 | 27 |

**M903 (0.50 Cal SLAP) Ballistics [2]**

| | | | | |
|---|---|---|---|---|
| Diameter | 0.3 | in | 0.762 | cm |
| Mass | 0.2094 | lbm | 0.0950 | kg |
| Velocity | 3999 | ft/s | 1219 | m/s |
| $K_2$ | 26.01 | ft ton | 70.58 | kJ |
| $A_2$ (front) | 0.0707 | $in^2$ | 0.4560 | $cm^2$ |
| $K_2/A_2$ | 367.9 | | 154.8 | $kJ/cm^2$ |

**ERDC Test Catchbox for M903**

| | |
|---|---|
| Width (ft) | 3.4 |
| Length (ft) | 6.9 |
| Height (ft) | 3.5 |
| Volume (cy) | 1.50 |
| Open angle (°) | 27 |

**M2 AP (0.50 Cal AP) Ballistics [3]**

| | | | | |
|---|---|---|---|---|
| Diameter | 0.5 | in | 1.27 | cm |
| Mass | 0.2588 | lbm | 0.1174 | kg |
| Velocity | 2808 | ft/s | 856 | m/s |
| $K_2$ | 15.85 | ft ton | 43.02 | kJ |
| $A_2$ (front) | 0.1963 | $in^2$ | 1.2668 | $cm^2$ |
| $K_2/A_2$ | 80.7 | | 34.0 | $kJ/cm^2$ |

**Physical Scaling**

| | |
|---|---|
| $K_1/K_2$ | 98.41 |
| $(K_1/A_1)/(K_2/A_2)$ | 13.84 |
| Scale Factor Used | 13.84 |
| $K_2/K_3$ | 1.64 |
| $(K_2/A_2)/(K_3/A_3)$ | 4.56 |

# Appendix B: Safety Plan for 50-caliber Shooting Project

5/14/08

**SAFETY PLAN**
**BALLISTIC SAND INVESTIGATION**
**BIG BLACK TEST SITE**
**ERDC/WES, VICKSBURG, MISSISSIPPI**

1. Purpose. The purpose of this safety plan is to outline the safety responsibilities and establish standard operating procedures that will be carried out during the firing of live ammunition into simulated firing berms consisting of ballistic sand at the Big Black Test Site (BBTS) during the 2$^{nd}$, 3$^{rd}$, and 4$^{th}$ quarters of FY 08.

2. Background. The ERDC Environmental Laboratory (EL) is currently investigating the extent of the dusting occurring during the live firing of the 0.50 caliber rifle with M903 Saboted Light Armor Penetrator (SLAP) ammunition, dispersed at military firing ranges. Team members from the ERDC Geotechnical and Structures Laboratory (GSL) are directly supporting this initiative through the use of the BBTS, SACON construction blocks, SACON backstop blocks, ERDC-qualified shooters, and storage facility for the ammunition. EL will be supplying the M903 SLAP ammunition through the Picatinney Arsenal. The procurement of the 0.50 caliber firing device will be a joint venture of the GSL and EL. The ERDC Information Technology Laboratory (ITL) will provide the support to record the height and distances that the ballistic sand and other debris are traveling upon impact of the M903 SLAP round.

3. Description of Investigation. The ballistic test portion of this evaluation will involve the firing of the M903 SLAP rounds into a scale model of the firing berms found at many military firing ranges throughout the US. The EL will be simulating the design and material used in a conventional 0.50 caliber firing range at Yuma Proving Grounds located in Yuma, AZ.

GSL will provide a suitable area at the BBTS to conduct this investigation. GSL will provide the SACON® construction blocks to form a single firing lane approximately 4-ft wide, 4-ft high, and 7-ft deep. The SACON® containment box will maintain an approximate 27-deg slope. The sloped section of the SACON® side-wall blocks will be saw-cut to remove any protrusions that may interfere with the direction and distances of the flying ballistic sand. The SACON® backstop blocks will be placed directed behind the berm, but outside the debris zone to capture any ricochets that may occur from the M903 SLAP round.

EL will provide the ballistic sand. EL will place a ground cover to capture the flying debris following each bullet impact. EL will replace and smooth the surface of the ballistic sand following each test firing. ITL will provide high-speed photographic equipment and personnel to record the flying ballistic sand and debris.

The GSL and EL will in a joint venture procure a firing device, universal bench receiver and 0.50 caliber barrel, to fire the M903 SLAP round. The firing device will be maintained by GSL for storage and future use in other investigations. The receiver will be table-mounted and securely fastened to provide accurate impact points into the ballistic sand. Sand bags or other weights will be used to secure the table during firing and during recoil of the firing device.

Approximately 10 rounds of standard M903 SLAP ammunition will be fired per week for 10 to 12 weeks into the scaled ballistic sand berm. The EL team members immediately following each test firing will record distances, determine mass of the particles, take photographs, and prepare the area for the next test firing. Approximately 100 to 120 rounds will be expended in this effort. Previous experiments with the 0.50 caliber ammunition fired into SACON® indicated that SACON® has the potential of allowing penetrations of 16- to 24-inches. The firing shall be conducted from an approximate distance of 200 feet (60 meters). The final firing distance will be depended upon the distance of the plastic sabot to travel from the barrel. The sabot round will not be allowed to hit the ballistic sand and cause further flying debris.

4. Responsibilities. Three persons shall be on site during any shooting exercise. One person shall serve as Project Engineer (PE), one person as Safety Officer (SO), and one person as First-Aid/CPR Attendant (CPR). A

list of designated team members for each position is presented in Table 1. The alternates may only serve one position as on-site team members; alternates cannot serve multiple positions/duties at the same time. The responsibilities of the PE are to ensure the achievement of the planned project objectives and to resolve any technical matters dealing with the designated certified firearm operators from the GSL and the firing device. The SO will represent the Commander and the Director of ERDC/WES during the investigation and will be responsible for the success of the project safety program and the initiation of this safety plan. The SO will be responsible for the geographic area surrounding the test area including the safety fan area of the firing device used. The SO is responsible for the establishment and maintaining the safety program outlined in this safety plan. The SO will be empowered to initiate quick and responsive on-the-spot corrective actions required of existing field conditions, actions, or situations of hazardous and unsafe working and testing conditions. The SO will ensure that all project team members comply with all safety requirements and criteria of this investigation. The CPR Attendant will be responsible for checking out and maintaining the respiratory protection and air monitoring equipment on site and in providing assistance and summoning help in the event of an injury on site. The certified firearms operators of the Structural Engineering Branch and the Concrete and Materials Branch will perform the shooting activities. Contract shooters, if used, shall be certified firearms operators with experience with US Military or state and local law enforcement. The ERDC/WES Legal Office shall review all contracts for proper liability clauses.

Table 1. Team members Designated to Operate as Project Engineers, Safety Officers, and First-Aid/CPR Attendant

| Project Engineers | Safety Officers | First-Aid/CPR Attendants |
|---|---|---|
| Mr. Joe G. Tom* | Dr. Victor Medina | Mr. Scott Waisner |
| Mr. Larry Garrett* | Mr. Scott Waisner | Mr. Joe G. Tom |
| Mr. Scott Waisner | Mr. Joe G. Tom | Dr. Victor Medina |

* ERDC Qualified Shooter

5. Firearm Safety. The firing device for this investigation will be a universal bench receiver mounted to a table or bench and securely weighted to absorb the firing and recoil of each test fire. The barrel will be a machined 0.50 caliber, 1 in 15-inch right twist bore, 29-inch length barrel without a muzzle brake; muzzle brake is considered unsafe for use with a sabot insert. The firing device will be a single-fire device. Each

shooter shall control and maintain the firing device at all times. The firing device will remain unloaded at all times until everyone is ready for the test firing. The chamber shall be cleared and checked after each test firing. The empty cartridge will be removed to indicate an empty chamber. An "All Clear" shall be conveyed to all team members onsite. The SO will supply the ammunition for each test firing; rounds not fired shall be returned to the SO when leaving the firing line. The firing device will be unloaded and secured with the chamber open when team members inspect the ballistic sand berm, debris, and SACON backstops down range.

6. Shooting Security. Immediately prior to each test firing, the safety fan area shall be visually surveyed to ensure the surrounding area is clear of other ERDC/WES team members working at the BBTS. The safety fan area shall include inspecting the Big Black River and riverbanks for boaters and hunters who may be entering the BBTS area. The SO shall verbally announce at the beginning of each test firing to all team members present at the BBTS Project Site. Immediately following the test firing, the shooter shall communicate to the SO relaying the "all-clear" signal and leave the firing line with device chamber open and clear. During each test firing, the SO shall monitor the immediate area for any encroachment from outside by anyone other than the immediate project team members. Public Affairs Office (PAO) at ERDC/WES and the Warren County Sherriff Department shall be notified before the daily shooting commences so that PAO team members can properly respond to any inquiries from neighbors around the BBTS.

7. Team members Safety Standards. All team members on the site shall be enrolled in a blood-testing program to monitor the exposure to lead and other respirable contaminants in the bullets and/or primers. The shooter and team members within the immediate area of the shooting shall be equipped with a supplied air system or, a respirator. Personal air monitoring devices capable of collecting respirable particulates shall be worn by the team members on the firing line as part of an air quality monitoring program and the program shall continue until such time as it can be established that the level of exposure produced by the ammunition being fired does not constitute a hazard to the shooter or team members working in the vicinity. All team members shall following the instruction of this safety plan, the safety program, and the verbal instructions of the SO when on-site. All team members shall immediately report any and all unsafe conditions pertaining to this investigation to the PE and the SO. All

team members on site shall render aid and assistance to any other team members requesting or needing aid and assistance. The minimum safety equipment for the shooters shall include safety glasses and hearing protection; safety shoes, gloves, hearing protection, and respiratory protection for team members; and hearing protection for all other observers and monitors. Ballistic resistant screens will be maintained in place to shield all shooters and other team members at the range area during firing. The First-Aid/CPR Attendant shall maintain a fully equipped first aid kit and fire extinguisher at all times. Good housekeeping rules aids in conducting a safe investigation and shall be observed by all on site team members. All areas shall be cleaned following each day of shooting. All spent shell casings shall be collected, cleaned, and returned to the PE for ammunition accountability.

8. Distribution. This safety plan shall be distributed to all team members associated with this field investigation.

9. References: EM 385-1-1, US Army Corps of Engineers Safety and Health Requirements Manual, 3 September 1996.

# Appendix C: MSDS for Durasoil®

## MATERIAL SAFETY DATA SHEET

### SECTION 1 - MATERIAL IDENTIFICATION

| | |
|---|---|
| PRODUCT NAME | DURASOIL*<br>*DURASOIL is a registered trademark of Soilworks, LLC. |
| MANUFACTURER | Soilworks, LLC.<br>681 North Monterey Street<br>Gilbert, Arizona 85233-8318 USA<br>www.soilworks.com |
| TELEPHONE NUMBER | 800-545-5420 |
| ONLINE INFORMATION | www.soilworks.com and www.durasoil.com |
| EMERGENCY TELEPHONE NUMBERS | 800-545-5420 (National & International) |
| REVISION DATE | March 2006 |

### EMERGENCY OVERVIEW

| | |
|---|---|
| PHYSICAL FORM | Bright clear viscous liquid |
| COLOR | Colorless |
| ODOR | Odorless |
| HAZARDS | This material is NOT HAZARDOUS according to the OSHA Hazard Communication Standard, 29 CFR 1910.1200. |
| C.A.S. CHEMICAL NAME | Product a blend. No number assigned |
| CHEMICAL NAME | Synthetic Organic Fluid For Dust Control |
| SYNONYMS | Dust Palliative, Dust Retardant, Dust Suppressant, Dust Control Material, Dust Inhibitor |
| CHEMICAL FAMILY | N/A |
| EMPIRICAL FORMULA | Mixture |
| INTENDED USE | Control Dust, Retard Dust, Suppress Dust, Inhibit Dust, Stop Dust, Reduce Dust, Eliminate Dust |
| REVISION NOTES | None |

### SECTION 2 - INGREDIENTS

| | Chemical Name | % | CAS Number |
|---|---|---|---|
| 1. | Complex mixture of severely hydrotreated, branched alkanes and alkylated saturated ring compounds | Trade secret | Non-hazardous |
| 2. | Proprietary ingredients | Trade secret | Non-hazardous |

### SECTION 3 – HAZARD IDENTIFICATION

**ROUTES OF EXPOSURE**

Skin, inhalation

Mist 8 hour ACGIH TLV: TWA 5mg/m$^3$

This product may cause irritation to the eyes, nose, throat, lungs and skin after prolonged or repeated exposure.

**CARCINOGENS UNDER OSHA, ACGIH, NTP, IARC**

None of the components present in this material at concentrations equal to or greater than 0.1% are listed by IARC, NTP, OSHA, or ACGIH as a carcinogen.

### SECTION 4 - FIRST AID

**EYE CONTACT**

Flush eyes with flowing water and continue flushing until irritation subsides. If irritation persists, seek medical attention.

**SKIN CONTACT**

Remove contaminated clothing. Wash affected area with soap and water. If redness or irritation occurs, seek medical attention.

**INHALATION**

This material has a low vapor pressure and is not expected to present an inhalation exposure at ambient conditions. If vapor or mist is generated when the material is heated or handled, move subject to fresh air. If breathing has stopped or is irregular, administer artificial respiration and supply oxygen if it is available. If subject is unconscious, remove to fresh air and seek immediate medical attention.

**INGESTION**

Do not induce vomiting due to aspiration hazard. Seek immediate medical attention.

### SECTION 5 - FIRE AND EXPLOSION DATA

| | |
|---|---|
| **FLASH POINT** | >300° F (>149° C) |
| **TEST METHOD** | ASTM D-93 (PMCC) |
| **FLAMMABLE LIMITS IN AIR** | No Data Available |
| **AUTOIGNITION TEMPERATURE** | No Data Available |

**EXTINGUISHING MEDIA**

Use dry chemical, foam, or carbon dioxide.

**SPECIAL FIRE FIGHTING PROCEDURES**

Water may be ineffective but can be used to cool containers exposed to heat or flame.

**UNUSUAL FIRE AND EXPLOSION HAZARDS**

Dense smoke may be generated while burning. Carbon monoxide, carbon dioxide, and other oxides may be generated as products of combustion.

## SECTION 6 - ACCIDENTAL RELEASE MEASURES

**CONTAINMENT TECHNIQUES**

Remove all sources of ignition. Stop the leak, if possible.

**CLEAN-UP PROCEDURES**

Wear suitable protective equipment. Contain spill immediately. Do not allow spill to enter sewers or open bodies of water. Absorb with inert absorbent materials. Large spills may be picked up using vacuum pumps, shovels, buckets, or other means and place in drums or other suitable containers.

## SECTION 7 - HANDLING AND STORAGE

**STORAGE**

Do not transfer to unmarked containers. Store in a cool, well ventilated area in closed containers away from heat, sparks, open flame or oxidizing materials.

**HANDLING**

Avoid breathing vapors or mist. Avoid contact with eyes. Avoid prolonged or repeated contact with skin. Wash thoroughly after handling. Wash clothing prior to reuse. May be slippery when spilled.

## SECTION 8 - PERSONAL PROTECTION / EXPOSURE CONTROLS

**EXPOSURE LIMITS AND GUIDELINES**

This product does not contain any components with OSHA or ACGIH exposure limits.
If mist is generated, exposure limits apply.

| | |
|---|---|
| OSHA PEL: | TWA 5 mg/m$^3$ |
| ACGIH TLV: | TWA 5 mg/m$^3$; STEL 10 mg/m$^3$ |

**EYE PROTECTION**

Eye protection is not required under conditions of normal use. If material is handled such that it could be splashed into eyes, wear splash-proof safety goggles.

**SKIN PROTECTION**

No skin protection is required for single, short duration exposures. For prolonged or repeated exposures, use impervious synthetic rubber (boots, gloves, aprons, etc.) over parts of the body subject to exposure (Nitrile recommended). Launder soiled cloths.

**RESPIRATORY PROTECTION**

Not required under normal conditions in a well-ventilated workplace. An organic vapor respirator National Institute for Occupational Safety and Health (NIOSH) approved for organic vapors is recommended where necessary to maintain exposure below the exposure limits.

**ENGINEERING CONTROLS**

If vapor or mist is generated when the material is heated or handled, adequate ventilation in accordance with good engineering practice must be provided to maintain concentrations below the specified exposure or flammable limits.

**WORK AND HYGIENIC PRACTICES**

Always wash hands and face with soap and water before eating, drinking, or smoking.

## SECTION 9 - TYPICAL PHYSICAL AND CHEMICAL PROPERTIES

| | |
|---|---|
| **PHYSICAL FORM** | Bright clear viscous liquid |
| **COLOR** | None, Colorless |
| **ODOR** | None, Odorless |
| **pH** | N/A, Not an aqueous solution |
| **VAPOR PRESSURE** | <1 (mm Hg) |
| **VAPOR DENSITY (Air = 1)** | >1 |
| **BOILING POINT** | >500° F (>260° C) |
| **MELTING POINT** | No Data Available |
| **SOLUBILITY IN WATER** | Insoluble in water |
| **SPECIFIC GRAVITY (Water = 1)** | 0.845 - 0.865 |
| **POUR POINT** | -5° F (-15° C) |

## SECTION 10 - STABILITY AND REACTIVITY

**CHEMICAL STABILITY**

Stable.

**CONDITIONS TO AVOID**

Heat, sparks, flame.

**INCOMPATIBILITY (Materials to Avoid)**

May react with strong oxidizing agents.

**HAZARDOUS DECOMPOSITION PRODUCTS**

Carbon monoxide, carbon dioxide, and other oxides may be generated as products of combustion.

**HAZARDOUS POLYMERIZATION**

Will not occur

## SECTION 11 - TOXICOLOGICAL PROPERTIES

**ACUTE ORAL TOXICITY (LD50, RAT)**

No Data

**ACUTE DERMAL TOXICITY (LD50, RABBIT)**

No Data

**ACUTE INHALATION TOXICITY (LC50, RAT)**

No Data

**OTHER ACUTE EFFECTS**

No Data

**IRRITATION EFFECTS DATA**

No Data

**CHRONIC/SUBCHRONIC DATA**

No Data

## SECTION 12 - ECOLOGICAL INFORMATION

No Data Available

## SECTION 13 - DISPOSAL CONSIDERATIONS

**REGULATORY INFORMATION**

All disposals must comply with federal, state and local regulations. The material, if spilled or discarded, may be a regulated waste. Refer to state and local regulations. Department of Transportation (DOT) regulations may apply for transporting this material when spilled.

**WASTE DISPOSAL METHODS**

Waste materials may be landfilled or incinerated at an approved facility. Materials should be recycled if possible.

## SECTION 14 - TRANSPORT INFORMATION

**U.S. DEPARTMENT OF TRANSPORTATION (DOT)**

| | |
|---|---|
| DOT NON-BULK SHIPPING NAME | Not Regulated |
| DOT BULK SHIPPING NAME | Not Regulated |

**INTERNATIONAL INFORMATION**

| | |
|---|---|
| VESSEL (IMO) SHIPPING DATA | Not Regulated |
| AIR (ICAO/IATA) SHIPPING DATA | Not Regulated |

## SECTION 15 - REGULATORY INFORMATION

### US FEDERAL REGULATIONS

**TOXIC SUBSTANCE CONTROL ACT (TSCA) 12(b) COMPONENT(S)**

None

**OSHA Hazard Communication Standard (29CFR1910.1200) hazard class(es)**

None

**EPA SARA Title III Section 312 (40CFR370) hazard class**

None

**EPA SARA Title III Section 313 (40CFR372) toxic chemicals above "de minimis" level are**

None

### CANADIAN REGULATIONS

This product is not a controlled product under the Canadian Workplace Hazardous Materials Information System (WHMIS).

## SECTION 16 – OTHER INFORMATION

The data in this Material Safety Data Sheet relates only to the specific material designated herein and does not relate to use in combination with any other material or in any process.

# Appendix D: Material Safety Data Sheet for TOPEIN®S

Issue Date: 4/08/99

## MATERIAL SAFETY DATA SHEET

## I. Product Identification

Product Name: TOPEIN®S Emulsions

Chemical Name: Emulsion of blended organic esters, surfactants, and water

CAS Number Mixture. See Section 3 – Regulatory Information

Chemical Formula Not applicable (see Section II)

Manufacturer Paramount Petroleum Bakersfield
1201 China Grade Loop
Bakersfield, CA. 93308
(661) 392-3630

Emergency Contact Phone: (602) 840-7702
Fax: (602) 840-3697

## II. Hazardous Ingredients

| Component | CAS | Approx wt % | ACGIH TLV | OSHA PEL |
|---|---|---|---|---|
| TOPEIN® (Sterol esters of $C_{18}$ and $C_{20}$ organic acids) | 8016-81-7 | 42-48 | None established | None established |
| Nonylphenol Polyethylene Glycol Ether Surfactant | Mixture | Proprietary | None established | None established |
| Hydrochloric acid | 7647-01-0 | <.25 | 7.5 mg/m$^3$ | 7 mg/m$^3$ |
| Water | 7732-18-5 | Approx 50 | N/A | N/A |

Hazardous Materials Identification System (HMIS)

| Health | Flammability | Reactivity |
|---|---|---|
| 1 | 0 | 0 |

(Least = 0, Slight = 1, Moderate = 2, High = 3, Extreme = 4)

## III. Physical Data

| | |
|---|---|
| Appearance and odor | Beige emulsion with bland odor |
| Molecular weight | Not applicable (mixture) |
| Boiling point | > 212 F |
| Melting point | Not available |
| Vapor pressure (torr) | Not available |
| Vapor density (air = 1) | Not available |
| Water content | Approximately 50% by weight |
| Evaporation rate | Not available |
| pH | 6-8 |
| Sp. Gravity (water = 1) | 1.00 – 1.008 |

### Fire and Explosion Data

| | |
|---|---|
| Flash point | Not available (> 200 F) |
| Flammable limits | LEL Not determined<br>UEL Not determined |
| Extinguishing media | Dry chemical, foam, carbon dioxide |
| Unusual fire and explosion hazards | None |
| Special fire fighting procedures | Avoid bodily contact. Use self-contained breathing apparatus in enclosed areas. |
| Hazardous combustion | Carbon dioxide and carbon monoxide. |

## IV. Reactivity Data

| | |
|---|---|
| Stability | Stable |
| Conditions to avoid | Stable at normal storage conditions |
| Incompatibilities (Materials to avoid) | Strong oxidizing agents; strong bases |
| Hazardous decomposition products | None known |
| Hazardous polymerization | Will not occur |

## V. Health Hazard Information

| | |
|---|---|
| Exposure from routine use | This product is not hazardous under normal conditions of use. |
| Probable routes of exposure | Skin, eyes, ingestion, inhalation |
| Emergency first aid | GET MEDICAL ASSISTANCE FOR ALL CASES OF OVEREXPOSURE<br>Skin: Flush thoroughly with large amounts of water; wash with soap and water.<br>Eyes: Flush thoroughly with water for at least 15 minutes<br>Inhalation: Remove to fresh air. Give artificial respiration if breathing has stopped.<br>Ingestion: Do not induce vomiting. If conscious, dilute by drinking large quantities of water; get medical attention. Never give anything by mouth to an unconscious person. |
| Acute effects | Corrosive material. Can cause irritation to skin, eyes, and mucous membranes. |
| Chronic effects | Repeated or prolonged exposure to liquid, vapor or mist may cause irritation in eyes, nose, mouth and/or throat. |
| Toxicity | No ingredients are listed by IARC, NTP, or OSHA as cancer causing agents. |

## VI. Ecological Information

Ecotoxicity TOPEIN® (CAS 8016-81-7)

| | |
|---|---|
| Acute fish toxicity (Zebra) | LC50 (96 h) > 400 mg/l |
| Growth inhibition studies (fresh water algae) | EC50 (72 h) > 1000 mg/l |
| Immobilization studies (Daphnia magna) | EC50 (48 h) > 2000 mg/l |
| Biodegradable | |

TOPEIN®S Emulsion

| | |
|---|---|
| Acute fish toxicity (fathead minnow) | LC50 (96h) > 750 mg/l |

## VII. Special Protection Information

| | |
|---|---|
| Personal Protective Equipment | Eye protection: face shield with chemical safety goggles<br>Protective gloves: rubber<br>Respiratory protection: none required under normal conditions of use<br>Other protective equipment: none |
| Ventilation | No additional ventilation required |
| Handling and Storing | Avoid skin and eye contact. Do not swallow. |

### Spill or Leak Procedures

| | |
|---|---|
| Steps to be taken in case of release or spill | Avoid skin contact. Use personal protective equipment as described above. Confine spillage and eliminate releases source if this can be done without risk. Spills of this material may trigger the emergency release reporting requirements. Dispose of all waste in accordance with federal, state, and local regulations. |

### Regulatory Information

This product is a mixture. Ingredients of this product are on the TSCA inventory. This mixture contains hydrochloric acid (CAS # 7647-01-0, <1.0%), which is subject to the reporting requirements of section 313 of SARA title III and 40 CFR Part 373. This product or any known constituent are not on California Prop 65 list.

## VIII. Comments

The information and data herein are believed to be accurate and have been compiled from sources believed to be reliable. It is offered for your consideration, investigation and verification. Buyer assumes all risk of use, storage and handling of the product in compliance with applicable federal, state and local laws and regulations. PARAMOUNT PETROLEUM BAKERSFIELD MAKES NO WARRANTY OF ANY KIND, EXPRESS OR IMPLIED, CONCERNING THE ACCURACY OR COMPLETENESS OF THE INFORMATION AND DATA HEREIN. THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE ARE SPECIFICALLY EXCLUDED. Paramount Petroleum Bakersfield will not be liable for claims relating to any party's use or reliance on information and data contained herein regardless of whether it is claimed that the information and data are inaccurate, incomplete or otherwise misleading.

# Appendix E: Workplan for Full-scale Study

DEPARTMENT OF THE ARMY
UNITED STATES ARMY YUMA PROVING GROUND
YUMA TEST CENTER
301 C STREET
YUMA, ARIZONA 85365-9498

REPLY TO ATTENTION OF

TEDT-YPY-CAC

13 April 2010

MEMORANDUM FOR U.S. Army Corps of Engineers, Engineer Research and Development Center (ERDC), ATTN: Dr. Victor F. Medina, 3909 Halls Ferry Road, Vickburg, MS 39180

SUBJECT: Budgetary Cost Estimate for YPG Support for the Depleted Uranium (DU) Ejecta Mitigation Study, U.S. Army Test and Evaluation Command (ATEC) Project No. 2010-DT-YPG-ARSPT-E7115

1. Reference. E-mail from Dr. Victor Medina (ERDC) to Mr. Pierre Bourque (this office), 17 February 2010, subject: DU Ejecta Work Plan.

2. In response to your request for support, we have prepared a cost estimate for the DU Ejecta Mitigation Study. The budgetary estimate is $119,292, which was calculated using FY10 rates and is based on conducting testing using facilities, equipment, and procedures in place at YPG. The breakdown for the estimate is shown in Table 1.

Table 1. DU Ejecta Mitigation Study Test Costs

| Category | Estimated Cost |
|---|---|
| Test Planning/Administration/Reporting | $6,785 |
| Test Preparation | $9,090 |
| Test Execution | $72,351 |
| Test Cleanup/Decontamination | $18,416 |
| Material/Consumables/Other (e.g., DU bioassays) | $12,650 |
| **Total** | **$119,292** |

LEGEND:
DU – Depleted Uranium

3. The Statement of Work for YTC is enclosed.

4. This estimate is accurate to the best of our knowledge. It is subject to change if the current scope of work changes or if events beyond our control should occur. If you agree that this estimate accurately reflects your test requirements, and agree to proceed with this work, I ask that you coordinate with the financial point of contact (POC) to transmit funds.

TEDT-YPY-CAC
SUBJECT: Budgetary Cost Estimate for YPG Support for the DU Ejecta Mitigation Study, ATEC Project No. 2010-DT-YPG-ARSPT-E7115

5. The financial POC is Ms. Eva Burgess of the Program Test Office, Resource Management, YPG. Her contact information is included below:

E-mail: Eva.Burgess@us.army.mil
Telephone: (928) 328-6806
DSN: 899-6806
Fax: (928) 328-6538

U.S. Army Yuma Proving Ground
Office Symbol: TEDT-YP-RMT
301 C Street
Yuma, AZ 85365-9498

6. The technical POC for your test program is Mr. Pierre Bourque at (928) 328-6221, fax: (928) 328-7707, or e-mail: Pierre.Bourque@us.army.mil. Please don't hesitate to call him with any questions you may have. We sincerely look forward to the opportunity to support your program.

L.F. BRACAMONTE
Director, Ground Combat Systems

Encl
Statement of Work

CF:
Resource Management (TEDT-YP-RMT) (w/encl)

STATEMENT OF WORK
Depleted Uranium (DU) Ejecta Mitigation Study

1. The test program will provide facilities and equipment in order to test the effect of a dust-palliative treatment on the amount of potentially DU-contaminated ejecta, as a result of the impact of a DU penetrator. YPG support includes coordination, setup, and test execution.

2. Eight standard 10-hour working days and two 10-hour overtime days were included for the firing portion of the test, and four 10-hour days were included to accommodate test cleanup and any necessary decontamination efforts. YPG has a four 10-hour day standard work week.

3. YPG will prepare and process all required documentation to include test plan, record of environmental consideration, frequency allocation requests, scheduling, safety review board, test report, and other administrative documentation required to support the test effort.

4. YPG will provide the 120-mm firing weapon, heavy equipment to support work at the catch box, meteorological (MET) data, and three high-speed cameras to collect test data. In accordance with (IAW) YPG radiation worker policies, the costs of DU bioassays for personnel working in the catch box area are included in this estimate.

Encl

## Work Plan

### Dust ejecta during DU penetrator impact on sand catch box

#### Background

Surveys conducted by the Army Range Technology Program (ART-P) around the GP-17 catch box at the Yuma Proving Grounds (YPG) indicate deposition of DU material is prevalent around the catch box. As part of the ART-P, the U.S. Army Engineer Research and Development Center (ERDC) has conducted studies on treatment approaches with water and dust palliatives in a small-scale catch box. ERDC proposes testing the principles learned on a full scale at YPG.

#### Objectives

The purpose of this study is to investigate the use of dust palliative additives at a full scale to reduce dust generation during full-scale 120-mm penetrator impact at the YPG catch box. By suppressing total ejecta, we believe DU deposition around the catch box will be reduced.

#### Study

*Overview*

The project will compare three different catchbox conditions:

1. Firing into dry media
    - Investigate current dust generation
    - Establish baseline
2. Firing into media prewetted prior to each shot
    - Can water reduce dust generation?
3. Firing into a palliative treated media
    - Use Durasoil®
    - Does palliative reduce dust generation?
    - Does palliative treatment continue to work over time (1 day)?

*Shots*

All shots will be conducted by YPG personnel under the guidance of Mr. Pierre Bourque. A total of 15 shots are anticipated. The shots could be

conducted with either a 105-mm or 120-mm gun – either would be acceptable. The shooting schedule will be:

- Day 2 – 3 shots into dry catch box to work on sampling approaches
- Day 3 – 3 shots into the dry catch box
- Days 4 and 5 – 3 shots into the catch box, wetted after each shot
- Day 7 – 3 shots into the Durasoil® treated catch box
- Day 9 – 3 shots into the Durasoil® treated catch box.

*Water addition*

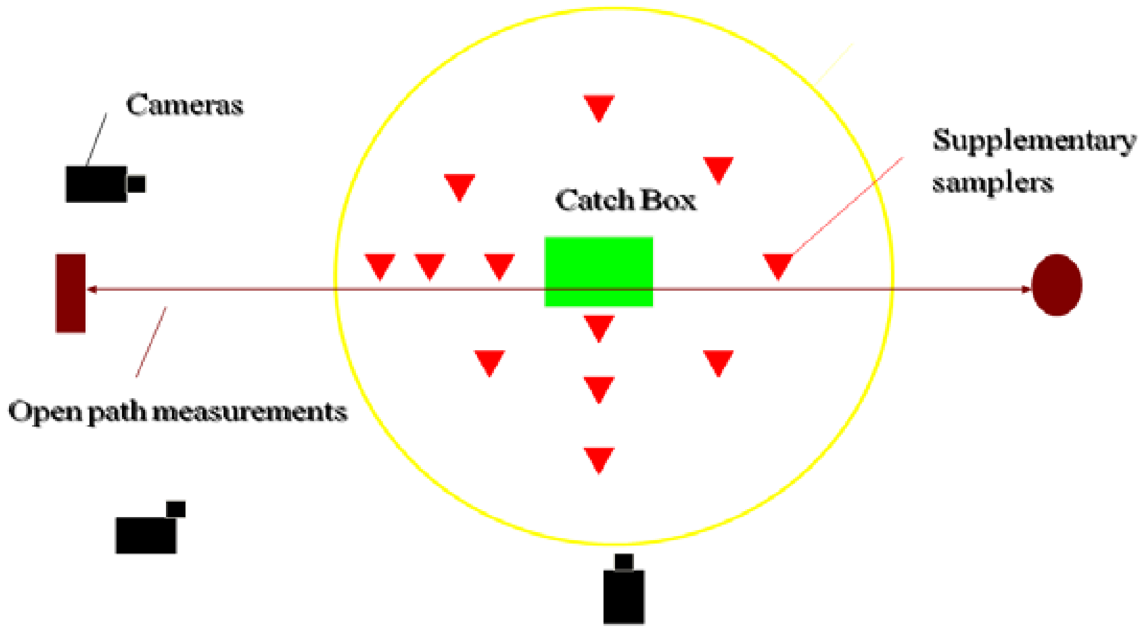
Water will be applied to a 3-x 3-m portion of the box surface to achieve an estimated 4% by weight water content at a depth of 0.5 m. This would require about 300 L (about 80 gal) of water. Water could be easily carried in 55-gallon drums and applied by Hudson sprayers. The 3-x 3-m test area will be marked by red access tape to allow the shooter a good target to aim for.

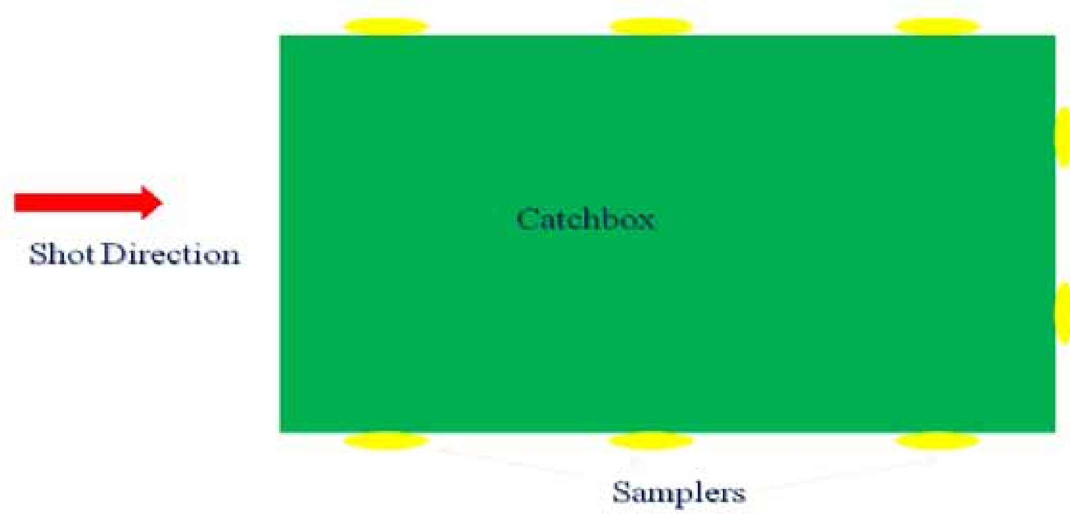
*Durasoil® addition*

Shallow pilings will be driven into the catch box surface by hand tools, and a 3-x3-x 0.5-m volume of sand will be excavated and placed on the surrounding surface in the catch box. Clean construction sand (13.5 $m^3$, about 18 $yd^3$) will be obtained prior to the test for delivery near the catch box. This will be mixed with Durasoil® to create a 1.25% by weight concentration. A total of about 115 L (about 30 gal) of Durasoil® will be required to treat this soil volume. Mixing will be conducted using a rented concrete mixer. The treated sand will be applied into the previously excavated 3-x 3-x 0.5-m block and the pilings will be removed. This area will be outlined by red access tape.

*Measurements*

The schematic below illustrates the proposed sampling plan.


Cameras
Supplementary
samplers
Catch Box
Open path measurements


Catchbox
Shot Direction
Samplers

Discrete sampling

For each test, clean sample filters will be placed in the existing ring of samples maintained by YPG. Eight elevated sticky sampler traps will also be placed (three on each side and two on the back edges of the catch box. Twelve sticky traps (0.5-m by 0.5-m) will be placed on the ground between the catch box and the existing sampling ring. These can be weighed before and after testing to find the captured mass, and the sticky material can be dissolved, allowing the material to be analyzed for uranium by Inductively Coupled Plasma Spectrophotometry.

In addition, arrays of inexpensive, precision cassette samplers (http://www.skcshopping.com/ProductDetails.asp?ProductCode=225-401) will be used to sample for fine particulates. These will require a vacuum air pump. These will be placed on the edges of the catch box using poles to collect from various heights. A control system will activate the pump. The cassettes can be weighed before and after to study total mass captured and the filters can be studied under an optical microscope to estimate particulate diameters. Further, the filters can be acid digested and analyzed for uranium. ERDC and Mississippi State University will work together to develop this sampling approach.

Video

Three high-speed digital video cameras will be set up to film the event. As shown in the schematic, these will be set in front, 90° to the side, and 45° oblique to the front of the catch box. In order to capture the full field of view, cameras will need to be set back 500 to 700 m from the catch box center. The cameras will be operated remotely and initiated by an acoustic trigger.

Test schedule

Estimates for each activity are given below.

- Setup -1 day
- Piloting study for instrumentation setup – 1 day
- Shoot into dry sand - 1 day
- Shoot into wet sand (wet after each shot) - 2 days
- Shoot into palliative (Durasoil®) treated sand – 3 days

  - 2 days to set up
  - 1 day shooting

- Second shots into palliative media – 1 day
- Close down, return to previous condition – 1 day

This gives a total time in the field as 10 days.

### Timeframe

In order to be prepared for all of the aspects of the test, proposed testing dates are 17 to 28 May 2010.

### Resources

*ERDC resources*

The ERDC work team is expected to consist of seven members. This will include a team of 5 or 6 people to conduct the sampling and prepare the sand treatments and 1 or 2 people to run video cameras.

*MSU resources*

MSU will provide a team to assist in the cassette sampling and to operate the open path measurements, if this option is chosen.

*YPG resources*

YPG will provide teams for shooting the DU penetrators as well as health and safety teams and radiation protection specialists.

### ERDC/MSU health and safety

ERDC and MSU will strictly follow the onsite health and safety plan from YPG. Some special considerations:

- The work at the catch box will require the use of air purifying respirators using particulate cartridges. All research team members who will work at the catch box will need to be medically cleared to wear a respirator. ERDC/MSU will provide respirators for their personnel. All must be fit-tested before going to the field. These would need to be fit-tested upon arrival in Yuma.

- All participants who will work in the catchbox area will need to undergo a before and after urine bioassay to monitor for metals and radionuclide uptake in the body. YPG can arrange for this. If ERDC and/or MSU conduct their own studies, the test must meet the approval of the YPG radiation safety officer.

**Checklist of required activities**

| Activity | Estimated Completion Date | Comments | Completed |
|---|---|---|---|
| **Preparation** | | | |
| Finalize dates with YPG | | May 17 start | yes |
| Confirm dates with MSU | | | yes |
| Confirm dates with ERDC team | | Waisner, Griggs, Beverly, Carter, Medina | yes |
| **Sticky Trap** | | | |
| Complete testing of sticky traps on reactor sides | | | Completed |
| Test sticky traps on ground | Week of 4/12 | | |
| Complete construction of sticky traps for field demo | 4/30/10 | | |
| **Digital Camera** | | | |
| Coordinate with ACE-IT for Phantom camera experts | 4/15/10 | | |
| **Durasoil®** | | | |
| Purchase request for Durasoil® | 04/5/10 | One 55-gal drum | |
| Purchase Durasoil® | 04/15/10 | We could also simply ship the remnants of the Durasoil® we currently have. | |
| Delivery to YPG | 05/10/10 | | |
| Arrange use of YPG mixer | 04/15/10 | Medina | |
| Arrange use of YPG backhoe or front loader | 04/15/10 | Medina | |
| **Filter Cartridge Sampling** | | | |
| Order any necessary cartridges/pumps | 04/15/10 | Check with MSU for resources | |
| Design & construct sampling equipment for edges of reactors | 04/30/10 | | |
| Test equipment | 05/15/10 | | |

| | | | |
|---|---|---|---|
| **Materials for Water Addition** | | | |
| Determine water delivery method | 04/15/10 | | |
| Deliver to YPG | 05/10/10 | | |
| **Health and Safety** | | | |
| Deliver YPG Health & Safety to all participants | 04/05/10 | | |
| Deadline for participants to review document | 04/30/10 | | |
| Deadline for health testing of participants for respirator use | 04/30/10 | | |
| Obtain respirators | 04/30/10 | | |
| Deadline for fit testing of respirators | 05/10/10 | | |
| Deadline for background urine bioassay | 05/17/20 | At YPG | |
| **Key Supplies** | | | |
| Sand form | 5/10/10 | | |
| Tyvek suits | 5/10/10 | Need to calculate how many are needed | |
| Rubber gloves | 5/10/10 | Heavy and disposable | |
| Work gloves | 5/10/10 | | |
| Shovels | 5/10/10 | | |
| Safety glasses | 5/10/10 | Include sunglass versions | |

## Daily Plan

| Day | Date | Activity(ies) | Resources | |
|---|---|---|---|---|
| 0 | 05/16/10<br>Sunday | Travel to from Vicksburg/Jackson to Yuma<br>Check into hotel | | |
| 1 | 05/17/10<br>Monday | Set Up<br>Goal – Get through all preparations: base access, safety, supplies, and site setup.<br>Registration activities at YPG<br>Badging<br>Safety video<br>Any additional rad safety<br>Bioassay<br>Kickoff meeting/work discussion<br>ERDC, MSU, & YPG personnel<br>Supplies<br>Inventory shipped supplies<br>Set up, organize<br>GPS base set up (MSU)<br>Mark locations for sampling<br>Measure off & mark locations for sticky traps<br>GPS locations<br>Mark locations of cartridge filter traps<br>Mark camera locations (YPG)<br>GPS<br>GPS locations of YPG ring samples | All personnel<br>MSU GPS team<br>MSU GPS Team<br>YPG Phantoms | |
| 2 | 05/18/10<br>Tuesday | Practice Shots<br>Goal – conduct practice shots to assess sampling locations & to get feel of experimental time.<br>Set up<br>Set up sticky samplers<br>Set up cartridge filters (MSU)<br>Set up Phantom cameras (YPG)<br>Shooting<br>1 shot<br>Observe results<br>Adjust setup as needed<br>Shoot again<br>Adjust<br>Shoot<br>Collect sampling equipment, police site<br>GPS any new locations | Phantom Cameras<br>Ammunition<br>MSU GPS Team | |

| | | | | |
|---|---|---|---|---|
| 3 | 5/19/10<br>Wednesday | Goal – Collect background data using refined sampling on penetrator impact into sand catch box<br>Set up<br>Set up sticky samplers<br>Set up cartridge filters (MSU)<br>Set up Phantom cameras (YPG)<br>Shooting<br>1 shot<br>Observe results<br>Collect and reinstall sampling equipment<br>Shoot again<br>Observe results<br>Collect and reinstall up sampling equipment<br>Shoot<br>Observe results<br>Collect sampling equipment, police site | | At 9 am – Briefing on ARTP results to YPG COL. Victor may need to attend. If so, then Scott will be in charge |
| 4 | 5/20/10<br>Thursday | Goal – Assess the effect of watering sand (4%) on sand ejecta<br>Set up<br>Set up sticky samplers<br>Set up cartridge filters (MSU)<br>Set up Phantom cameras (YPG)<br>Watering – add water to reach 4% (estimated)<br>Shooting<br>1 shot<br>Observe results<br>Collect and reinstall up sampling equipment<br>Watering<br>Assess if needed<br>Addition<br>Shoot again<br>Observe results<br>Collect and reinstall up sampling equipment<br>Watering<br>Assess if needed<br>Addition<br>Shoot<br>Observe results<br>Collect sampling equipment, police site | Water truck with sprayer (300 gal)<br>Water truck | |

| | | | | |
|---|---|---|---|---|
| 5 | 05/21/10<br>Friday | Complete water addition work<br>Begin Durasoil® treatment<br>Batches of sand into mixer<br>Add appropriate amount of Durasoil®<br>Mix for 10 minutes<br>Stage treated soil<br>Repeat as needed | Water truck (YPG)<br>Construction grade sand (ERDC arrange delivery)<br>Buckets (ERDC)<br>Shovels (ERDC)<br>Drum(s) of Durasoil® (ERDC)<br>Mixer (YPG)<br>Water truck (YPG) | |
| 6 | 5/22/10<br>Saturday | Complete Durasoil® Treatment<br>Batches of sand into mixer<br>Add appropriate amount of Durasoil®<br>Mix for 10 minutes<br>Stage treated soil<br>Repeat as needed<br>Set form for digging out soil<br>Begin digging out patch from catch box | Construction grade sand<br>Drum(s) of Durasoil®<br>Buckets (ERDC)<br>Shovels (ERDC)<br>Mixer<br>Water truck<br>Sheet metal form (ERDC)<br>Rotohammers (ERDC)<br>Shovels (ERDC)<br>Buckets (ERDC)<br>Backhoe with bucket | PPE |
| 7 | 5/23/10<br>Sunday | Day off | Nothing | |
| 8 | 5/24/10<br>Monday | Goal – prepare for Durasoil® test<br>Complete digging out patch from catch box<br>Put in Durasoil® treated sand | Shovels (ERDC)<br>Buckets (ERDC)<br>Backhoe with bucket<br>Shovels (ERDC)<br>Buckets (ERDC)<br>Backhoe with bucket | PPE<br>PPE |
| 9 | 5/25/10<br>Tuesday | Durasoil® shots<br>Goal – Test Durasoil® for ability to suppress ejecta<br>Set up<br>Set up sticky samplers | | |

| | | | | |
|---|---|---|---|---|
| | | Set up cartridge filters (MSU)<br>Set up Phantom cameras (YPG)<br>Shooting<br>1 shot<br>Observe results<br>Collect and reinstall up sampling equipment<br>Shoot again<br>Observe results<br>Collect and reinstall sampling equipment<br>Shoot<br>Observe results<br>Collect sampling equipment, police site | | |
| 10 | 05/26/10<br>Wednesday | Second Durasoil® shots<br>Goal – Test Durasoil® for ability to suppress ejecta for >1 day.<br>Set up<br>Set up sticky samplers<br>Set up cartridge filters (MSU)<br>Set up Phantom cameras (YPG)<br>Shooting<br>1 shot<br>Observe results<br>Collect and reinstall up sampling equipment<br>Shoot again<br>Observe results<br>Collect & re set up sampling equipment<br>Shoot<br>Observe results<br>Collect sampling equipment, police site | | |
| 11 | 05/27/10<br>Thursday | Goal – return site to previous condition and ship samples/equipment back to Vicksburg<br>Dig out Durasoil® treated sand<br>Return original sand<br>Concurrently – pack supplies and samples and ship | Backhoe<br>Backhoe<br>Water for decon | |
| 12 | 05/28/10<br>Friday | Return home | | |

# Appendix F: Email Confirmation that Durasoil® Would Not Adversely Affect the Disposal Status of Catch Box Sand

Classification: UNCLASSIFIED
Caveats: NONE

Hi Victor,

Army Rad Waste has determined the Durasoil treated sand does not constitute a mixed waste, therefore we will be able to dispose of the treated sand as planned.

Thanks,
Mary

Mary Svoboda
Health Physicist
A-P-T Research, Inc.
Supporting Yuma Proving Ground

(928) 328-2444 DSN 899
Cell: (928) 920-9857

-----Original Message-----

From: Medina, Victor F ERDC-EL-MS [mailto:Victor.F.Medina@usace.army.mil]
Sent: Wednesday, October 14, 2009 3:26 PM
To: Bourque, Pierre P Mr CIV USA ATEC; Svoboda, Mary B CTR USA ATEC
Subject: FW: Burn test of Durasoil on sand (UNCLASSIFIED)

Pierre and Mary,

It looks like we passed the test. Am I correct?

Victor

Victor F. Medina, Ph.D., P.E.
Team Leader: Environmental Security Engineering Principal Investigator & Environmental Engineer U.S. Army Corps of Engineers Engineer Research & Development Center

3909 Halls Ferry Rd.
Vicksburg, MS 39180

601 634 4283
fax 601 634 3518
cell 601 831 7251

victor.f.medina@us.army.mil
http://el.erdc.usace.army.mil/bios.cfm?Id=Medina-EP-E

-----Original Message-----

From: Crooks, Kelly CIV USA AMC [mailto:kelly.crooks@us.army.mil]
Sent: Tuesday, October 13, 2009 10:13 AM
To: Svoboda, Mary B CTR USA ATEC
Cc: Medina, Victor F ERDC-EL-MS

Subject: RE: Burn test of Durasoil on sand (UNCLASSIFIED)

Not a problem.

Kelly W. Crooks
Joint Munitions Command
AMSJM-SF
Rock Island, IL 61299-6000

com (309) 782-0338
DSN 793-0338
cell (309) 716-8796
fax (309) 782-2988

-----Original Message-----

From: Svoboda, Mary B CTR USA ATEC
Sent: Thursday, October 08, 2009 3:29 PM

To: Crooks, Kelly CIV USA AMC
Cc: Medina, Victor F ERDC-EL-MS

Subject: FW: Burn test of Durasoil on sand (UNCLASSIFIED)

Classification: UNCLASSIFIED
Caveats: NONE

Kelly,

Dr. Medina and the research group at ERDC performed some flammability studies on the Durasoil mixture that will be tested at YPG. Please let us know if you think the findings will negatively impact our ability to dispose of the waste material.

Thanks again for your assistance...

Mary

Mary Svoboda
Health Physicist
A-P-T Research, Inc.
Supporting Yuma Proving Ground

(928) 328-2444 DSN 899
Cell: (928) 920-9857

# REPORT DOCUMENTATION PAGE

*Form Approved OMB No. 0704-0188*



| **1. REPORT DATE** ***(DD-MM-YYYY)*** | **2. REPORT TYPE** | **3. DATES COVERED** ***(From - To)*** |
|---|---|---|
| April 2012 | Final report | |

**4. TITLE AND SUBTITLE**

Methods to Reduce Sand Ejecta from Projectile Impact – a Scaled Study with the Goal of Application to Depleted Uranium Penetrator Catch Boxes

**5a. CONTRACT NUMBER**

**5b. GRANT NUMBER**

**5c. PROGRAM ELEMENT NUMBER**

**6. AUTHOR(S)**

Victor F. Medina and Scott A. Waisner

**5d. PROJECT NUMBER**

**5e. TASK NUMBER**

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**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**

Environmental Laboratory
U.S. Army Engineer Research and Development Center
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

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**12. DISTRIBUTION / AVAILABILITY STATEMENT**

Approved for public release; distribution is unlimited.

**13. SUPPLEMENTARY NOTES**

**14. ABSTRACT**

Depleted uranium (DU) is used in three penetrator munitions by the U.S. Army, a 25-mm round (M242), 105-mm antitank rounds (M900, M774, M833), and 120-mm antitank rounds (M829, M829A1, M829A2). The last two of these munitions are frequently fired into large catch boxes at two proving grounds – Yuma Proving Ground near Yuma, AZ and the Aberdeen Proving Ground, MD. Gamma radiation surveys indicate that during penetrator impact DU ejecta in particulate material are deposited around catch boxes.

A scaled version of the catch box was constructed using SACON® concrete blocks and construction grade sand. Testing consisted of firing a three-shot salvo from a 50-caliber, Barrett Rifle using standard ball ammunition. Both high-speed Phantom and digital video cameras were used to capture ejecta images during the impact. Ejected sand settled on the capture tarp, where it was collected after shots.

Results indicated that use of water misters did not substantially reduce ejecta compared to untreated sand. The direct addition of water had confusing results. In some cases, directly irrigating the sand substantially reduced ejecta, but in other cases, it actually seemed to increase ejecta. A geotechnical slump study determined that 4% was the maximum amount of water that could be added to the sand without "strengthening" it. Testing with the 4% water addition produced consistent results, with 97% reduction of sand ejecta from untreated sand. In addition, efforts to intentionally compact the sand bed resulted, as expected, in large increases of sand ejecta.

The next phase of testing focused on the use of two dust palliatives, Durasoil® and TOPEIN-S®. The 1.25% Durasoil® worked as well as water and retained its effective performance after 11 days. When first applied, TOPEIN-S® worked well; however, after 1 month of weathering, it appeared that TOPEIN-S® behaved similarly as when too much water was added or when the bed was compacted.

**15. SUBJECT TERMS**

Depleted uranium
Durasoil®
Penetrator munitions
Projectile impact
TOPEIN-S®

| **16. SECURITY CLASSIFICATION OF:** | | | **17. LIMITATION OF ABSTRACT** | **18. NUMBER OF PAGES** | **19a. NAME OF RESPONSIBLE PERSON** |
|---|---|---|---|---|---|
| **a. REPORT** | **b. ABSTRACT** | **c. THIS PAGE** | | | **19b. TELEPHONE NUMBER** ***(include area code)*** |
| UNCLASSIFIED | UNCLASSIFIED | UNCLASSIFIED | | 81 | |

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